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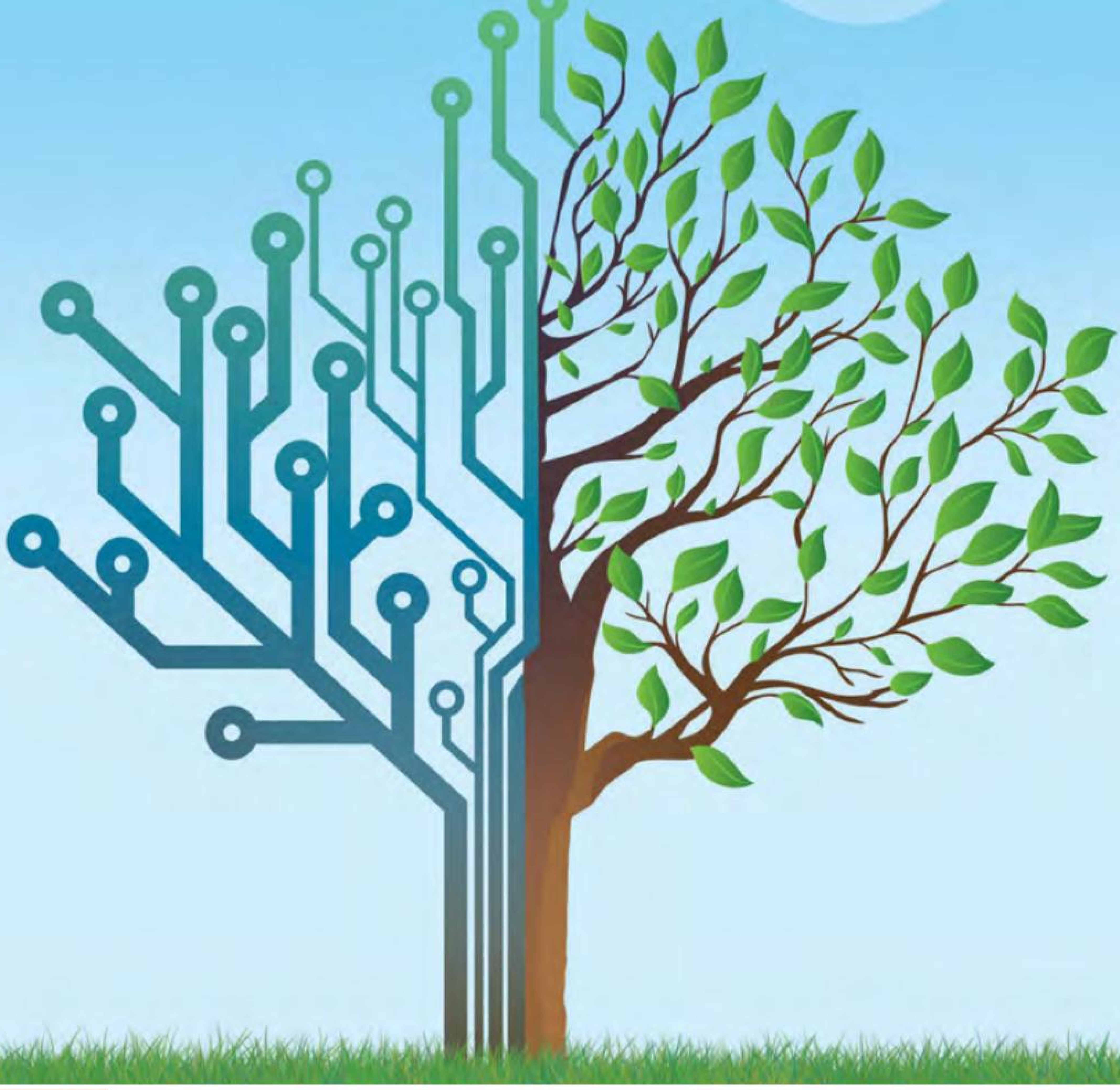

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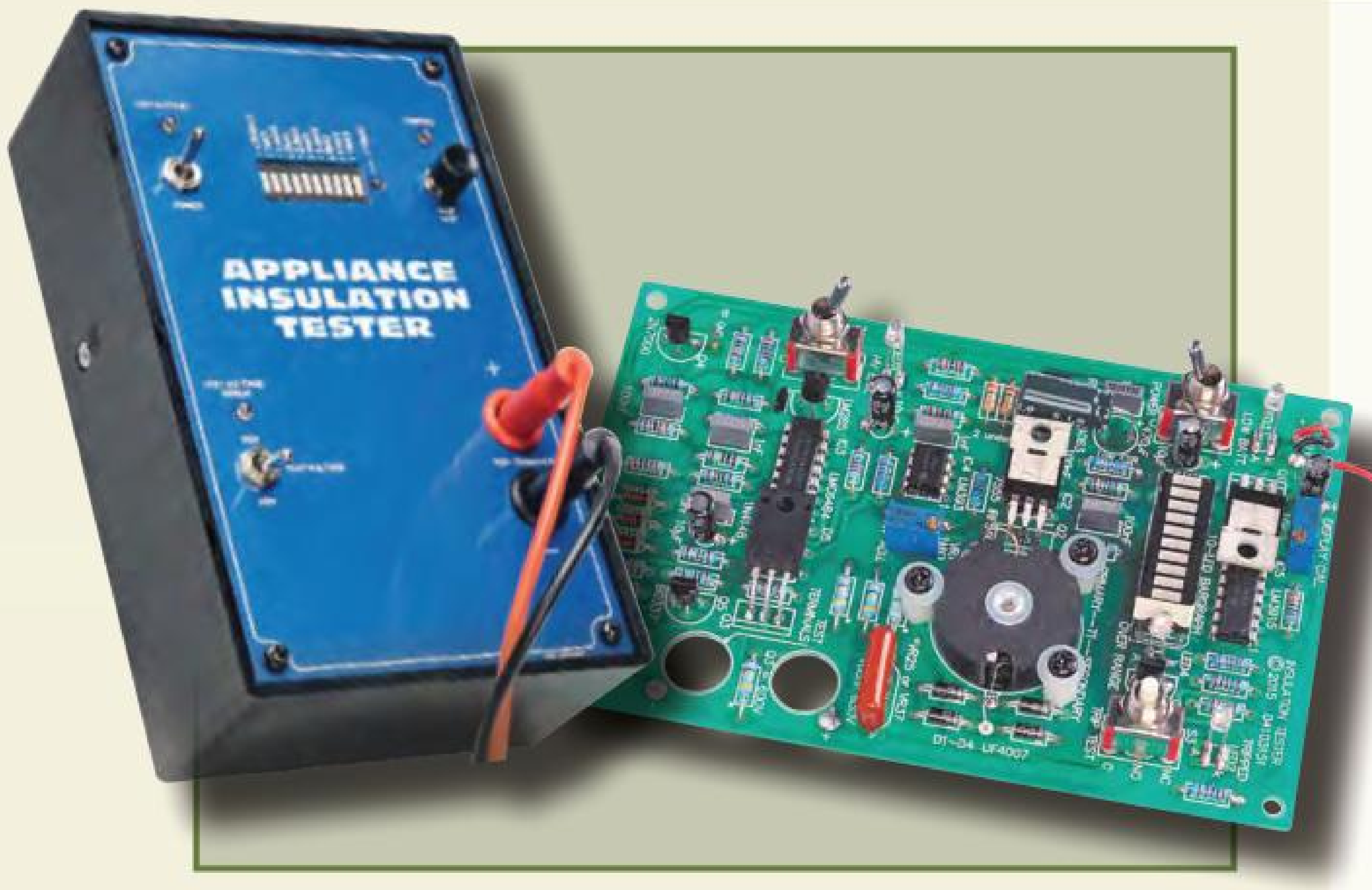
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Our May 2016 issue will be published on Thursday 7 April 2016, see page 80 for details.

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Controllers & Loggers

Here are just a few of the controller and data acquisition and control units we have. See website for full details. 12Vdc PSU for all units: Order Code 660.446UK £11.52

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5 digital input channels and 8 digital output channels plus two analogue inputs and two analogue outputs with 8 bit resolution.
*Kit Order Code: K8055N - **£25.19***
*Assembled Order Code: VM110N - **£40.20***

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*Kit Order Code: 8157KT - **£49.95***
*Assembled Order Code: AS8157 - **£54.95***

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Serial port 4-channel temperature logger. °C or °F. Continuously logs up to 4 separate sensors located 200m+ from board. Wide range of free software applications for storing/using data. PCB just 45x45mm. Powered by PC. Includes one DS1820 sensor.
*Kit Order Code: 3145KT - **£19.95***
*Assembled Order Code: AS3145 - **£26.95***
*Additional DS1820 Sensors - **£4.95 each***

Remote Control Via GSM Mobile Phone

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Place next to a mobile phone (not included). Allows toggle or auto-timer control of 3A mains rated output relay from any location

Most items are available in kit form (KT suffix) or pre-assembled and ready for use (AS prefix).

4-Ch DTMF Telephone Relay Switcher

Call your phone number using a DTMF phone from anywhere in the world and remotely turn on/off any of the 4 relays as desired. User settable Security Password, Anti-Tamper, **Rings** to Answer, Auto Hang-up and Lockout. Includes plastic case. 130 x 110 x 30mm. Power: 12Vdc.
*Kit Order Code: 3140KT - **£79.95***
*Assembled Order Code: AS3140 - **£94.95***

8-Ch Serial Port Isolated I/O Relay Module

Computer controlled 8 channel relay board. 5A mains rated relay outputs and 4 opto-isolated digital inputs (for monitoring switch states, etc). Useful in a variety of control and sensing applications. Programmed via serial port (use our new Windows interface, terminal emulator or batch files). Serial cable can be up to 35m long. Includes plastic case 130x100x30mm. Power: 12Vdc/500mA.
*Kit Order Code: 3108KT - **£74.95***
*Assembled Order Code: AS3108 - **£89.95***

Infrared RC 12–Channel Relay Board

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*Assembled Order Code: AS3142 - **£74.95***

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*Kit Order Code: 3153KT - **£37.95***
*Assembled Order Code: AS3153 - **£49.95***

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Kit Order Code: 8191KT - £29.95
Assembled Order Code: AS8191 - £39.95

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Here are a few of the most recent products added to our range. See website or join our email Newsletter for all the latest news.

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Assembled Order Code: AS3190 - ***£99.95***

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Kit Order Code: 3187KT - ***£39.95***
Assembled Order Code: AS3187 - ***£49.95***

Video Signal Cleaner

Digitally cleans the video signal and removes unwanted distortion in video signal. In addition it stabilises picture quality and luminance fluctuations. You will also benefit from improved picture quality on LCD monitors or projectors.
Kit Order Code: K8036 - ***£24.70***
Assembled Order Code: VM106 - ***£36.53***

Motor Speed Controllers

Here are just a few of our controller and driver modules for AC, DC, Unipolar/Bipolar stepper motors and servo motors. See website for full details.

DC Motor Speed Controller (100V/7.5A)

Control the speed of almost any common DC motor rated up to 100V/7.5A. Pulse width modulation output for maximum motor torque at all speeds. Supply: 5-15Vdc. Box supplied. Dimensions (mm): 60Wx100Lx60H.
Kit Order Code: 3067KT - ***£19.95***
Assembled Order Code: AS3067 - ***£27.95***

Bidirectional DC Motor Speed Controller

Control the speed of most common DC motors (rated up to 32Vdc/10A) in both the forward and reverse direction. The range of control is from fully OFF to fully ON in both directions. The direction and speed are controlled using a single potentiometer. Screw terminal block for connections.
Kit Order Code: 3166v2KT - ***£23.95***
Assembled Order Code: AS3166v2 - ***£33.95***

Computer Controlled / Standalone Unipolar Stepper Motor Driver

Drives any 5-35Vdc 5, 6 or 8-lead unipolar stepper motor rated up to 6 Amps. Provides speed and direction control. Operates in stand-alone or PC-controlled mode for CNC use. Connect up to six 3179 driver boards to a single parallel port. Board supply: 9Vdc. PCB: 80x50mm.
Kit Order Code: 3179KT - ***£17.95***
Assembled Order Code: AS3179 - ***£24.95***

Computer Controlled Bi-Polar Stepper Motor Driver

Drive any 5-50Vdc, 5 Amp bi-polar stepper motor using externally supplied 5V levels for STEP and DIRECTION control. Opto-isolated inputs make it ideal for CNC applications using a PC running suitable software. Board supply: 8-30Vdc. PCB: 75x85mm.
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Assembled Order Code: AS3158 - ***£34.95***

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Kit Order Code: 1074KT - ***£15.95***
Assembled Order Code: AS1074 - ***£23.95***

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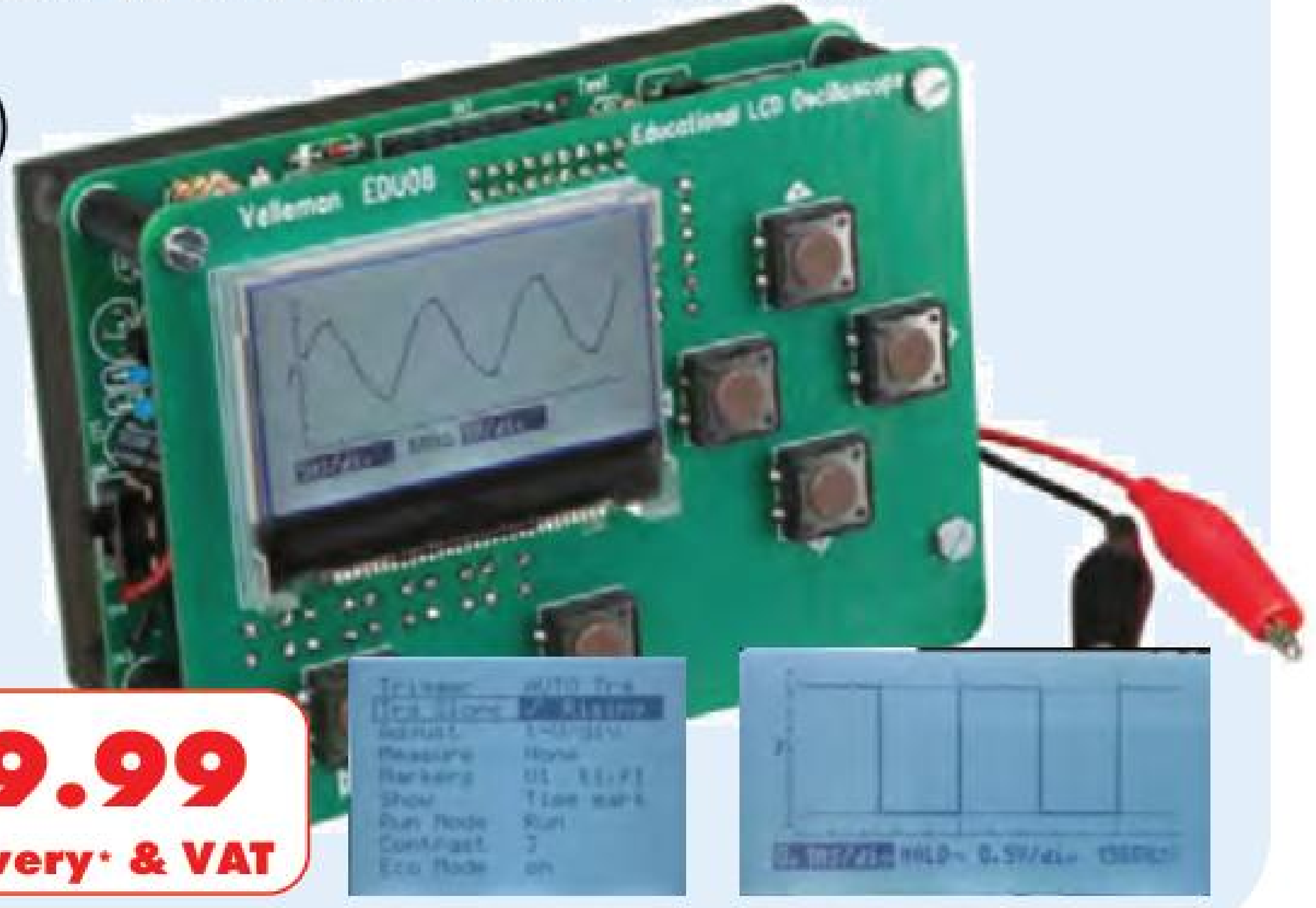

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All reasonable precautions are taken to ensure that the advice and data given to readers is reliable. We cannot, however, guarantee it and we cannot accept legal responsibility for it.

A number of projects and circuits published in EPE employ voltages that can be lethal. You should not build, test, modify or renovate any item of mains-powered equipment unless you fully understand the safety aspects involved and you use an RCD adaptor.

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We do not supply electronic components or kits for building the projects featured, these can be supplied by advertisers.

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EPE EVERYDAY PRACTICAL ELECTRONICS

Welcome to April's issue – as always, your favourite electronics magazine is packed with projects, analysis, explanations and news. Each of us has our own particular interests, and I especially enjoyed the insulation project and this month's *Teach-In* and *Circuit Surgery* columns.

Test that insulation!

Our *Appliance Insulation Tester* is not just interesting, but also useful. It may not have the 'glamour' of a high-end bells-and-whistles amplifier, but if it warns you just once about a faulty appliance it will have fully repaid any investment in time and money. It works with both double-insulated and conventionally earthed appliances and power tools. However, the one thing it doesn't do is apply 230V AC mains voltage and so it cannot test appliances that have a 'soft' or non-mechanical power switch (eg, DVD players and TVs). Never fear, next month we will feature an *Appliance Earth Leakage Tester* as a companion instrument to fill that gap.

Strings and things

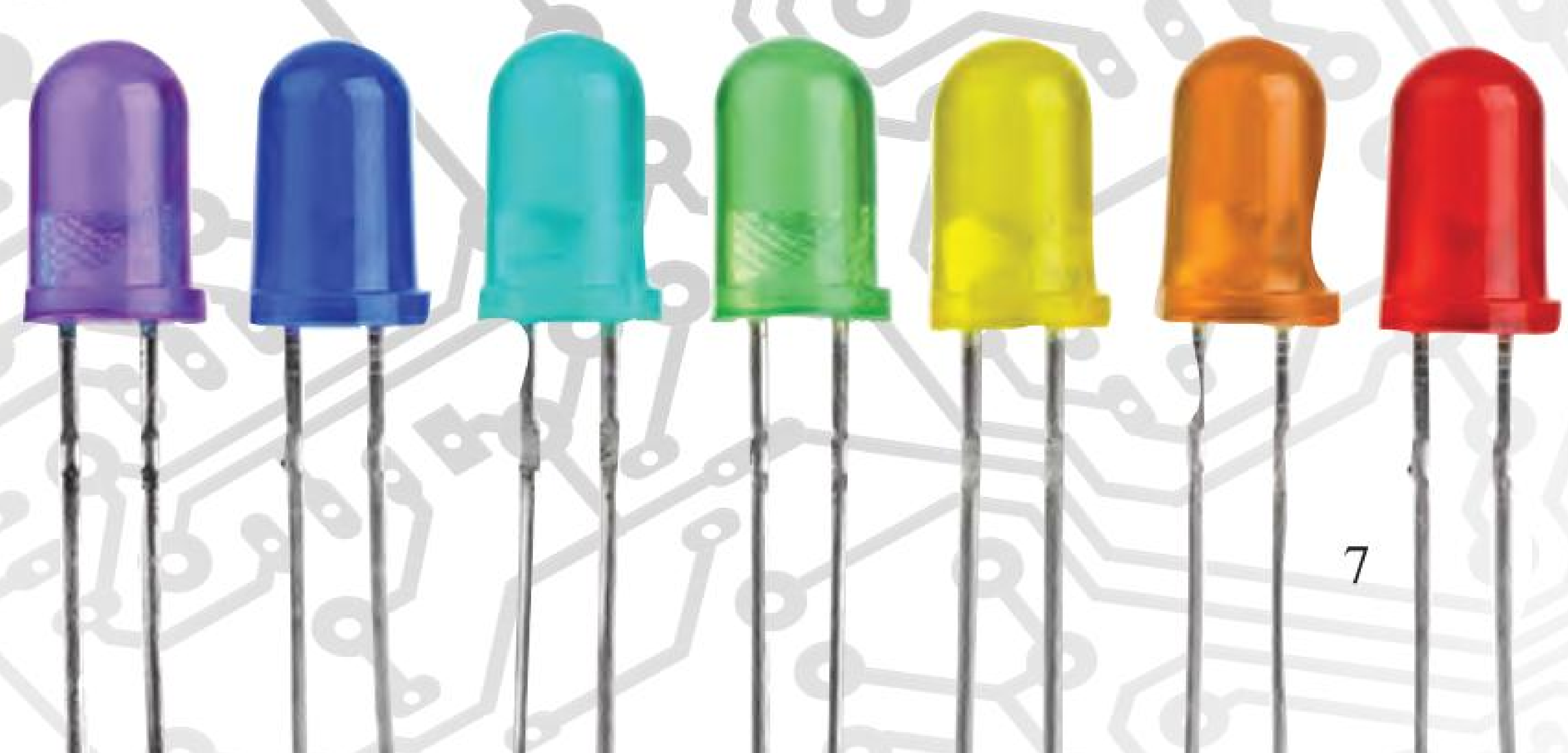
Our Arduino-themed *Teach-In* series continues with a detailed look at Arduino-friendly displays and indicators. We get to grips with arrays and strings, how to manipulate them and use that knowledge to build an access control system. We're only at Part 3 of *Teach-In 2016*, but already you should be able to put together some interesting Arduino-based designs.

Ebers-Moll

Who?! Jewell James Ebers and John Moll, that's who. In 1954 this duo introduced a famous – and still widely used – mathematical model of transistor currents. At the heart of the Ebers-Moll model is a (relatively) simple equation, which is commonly used to explain the operation of transistors and transistor circuits – for example, the long-tailed pair difference amplifier. In this month's *Circuit Surgery*, Ian Bell explains the operation of the bandgap reference voltage circuit using the Ebers-Moll model. It's a particularly elegant design and well worth understanding. It does involve some mathematics, and if your logarithms and exponential functions are a little rusty then it's worth refreshing your understanding over at: **www.mathsisfun.com/algebra/exponents-logarithms**

LIGO

The day I chose to write this editorial happens to be the one researchers announced the detection of gravity waves. It is not only an extraordinary intellectual achievement, but also a fantastic feat of engineering, especially in the fields of electronics and sensing. The brief to the designers of 'LIGO', the laser interferometer used at the heart of the experiment, was to measure a change in length so small it was equivalent to the diameter of a football over the width of the Milky Way – almost unimaginable accuracy, and just one of many examples of how electronics continues to astonish and inspire us.



NEWS

A roundup of the latest Everyday News from the world of electronics

Second chance for Blu-ray? – report by Barry Fox

Blu-ray did not take off as well as the industry hoped, because too many people rate online instant access over picture and sound quality. But few broadband connections can reliably stream 4K UHD, so Blu-ray has another chance with BD UHD.

BD standard

The new BD standard, which was set last August and runs to 1200 pages, covers discs with higher data density per layer (33GB instead of 25GB) and more layers (up to three instead of two). But so far there have been no triple layer 100GB BDs.

A post-CES briefing by MESA Europe, the Media and Entertainment Services Alliance, held recently at the Ray Dolby Theatre, Soho Square in London went some way towards clarifying the confused picture on 100GB viability. It also inadvertently highlighted the movie industry's paranoia over releasing studio master quality movies on BD.

Reaching 100GB

Seth Hallen, Senior Vice President Creative Services, Sony DADC New Media Solutions in Culver City and Wolfgang Diemling, Director Mastering, Sony DADC in Austria, confirmed their company currently has 18 UHD BD projects under way, with the first commercial releases slated for March 2016 to coincide with the expected launch of Samsung's UHD BD player. However, all these releases will be on double-layer 66GB discs, with production capacity of Sony's plant in Austria currently running at 50,000 discs per day.

There has been 'a lot of discussion' about 100GB triple layer test discs, Hallen said. 'The first test discs have been successfully created', he said. The first 100GB releases will be 'offered by the end of August 2016' said Wolfgang Diemling.

The reason for the delay, he explained, is that although double layer 66GB disc production needs no special equipment, other than new optics to handle the use of shorter data pit length, which increases layer density to 33GB, triple layering needs 'major investment in expensive new presses, with secondary embossing and sputtering equipment, which all creates a bigger footprint'. The cycle time for triple layer production is also less favourable, and the final disc must be hard-coated for protection.

There is also still a 'missing link'; there is no UHD PC drive yet available and these are needed for image analysis QC testing.

Piracy protection

To meet the movie studio's concern over piracy risks, the new UHD BD discs will use AACS2 copy protection, which provides for network-authorised, time-based release. A consumer player will go online to receive the keys needed to unlock disc play on an authorised release date.

Elfed Howells, Director, Business Development EMEA, Dolby Europe kicked off the MESA conference by trying to demonstrate how video has progressed over the last decade from DVD to BD to UHD. Using the Dolby theatre's laser projector, Howells screened DVD and BD clip versions of Tomorrowland, but regretted that he could not show the same clip in UHD with High Dynamic Range pictures because of 'content rights issues'. So he had to show a Dolby CGI promo instead.

Both David Millar and Jim Bottoms of MESA then encouraged delegates to attend demonstrations of Dolby Atmos immersive sound and DolbyVision HDR after the main proceedings, in side rooms set up by Dolby and using new Vizio HDR TVs brought in from the US. The content included impressive clips from Mad Max in UHD HDR, they said.

One party of delegates was duly given the demonstration but further sessions were abruptly cancelled on orders received from the content providers. The audience would have included three media journalists who had attended the main event, and the content owners wanted on-the-spot approval of the Dolby screen setup.

Meanwhile Jamie Hindhaugh, Chief Operating Officer, BT Sport & BT TV told of BT's experiences with covering sport live in 4K since launching 'Europe's very first live sports Ultra HD channel' last August.

'HDR has the potential to derail what's currently been really good take-up of 4K' Jamie Hindhaugh warned. 'The consumer is getting confused over whether it's the right time to buy a TV. The backwards compatibility thing is a real issue.'

Consumer confusion

'The marketing and the messaging and the language is so messy, with so many acronyms,' he went on. 'We have always been an acronym-heavy industry, but it's got so much worse. No disrespect to your colleagues in the UHD Alliance (who had just been seen enthusing in a video of their panel discussion at CES) but they were getting themselves confused at times and saying it's great

Second chance for Blu-ray? *continued*

having the UHD Premium mark because 'we can unlock all the TVs out there'. Well they're not out there because they haven't been made yet.

'It's really confusing. Even very senior people who should know what they are talking about are getting baffled. It's really important that we make it really simple for the consumer so when the content does come it can be properly enjoyed and there's not a whole army of consumers who are confused and upset they have bought something wrong.'

Andy Beale, Chief Engineer, BT Sport agreed and condemned 'the complexity around this, and the constant drive for people to refresh their TVs. We need to be careful, otherwise no-one will,' he warned.

Contact lens electronics breakthrough

A polymer film coating with the ability to turn contact lenses into computer screens is set to transform wearable visual aids into the next generation of consumer electronics.

Scientists from the University of South Australia's Future Industries Institute (FII) have successfully completed 'proof of concept' research on a polymer film coating that conducts electricity on a contact lens, with the potential to build miniature electrical circuits that are safe to be worn by a person.

FII researcher Associate Professor Drew Evans said the technology could provide one of the safest methods to bring people and their smart devices closer together.

'We're talking about anything from a simple sensor that can measure the amount of glucose in your blood through to actually creating electronic displays so rather than having something like a pair of glasses that's acting like a computer, you can actually generate images directly on your contact lens,' Evans said.

Computer Conservation Society competition

Joint-winner of 2014, IBM 1401 Demo Lab in the Computer History Museum, California

Nominations are invited for the 2016 Tony Sale Award for Computer Conservation. The award recognises achievements in computer conservation or restoration, and is open to any individual or group anywhere in the world.

Managed by the Computer Conservation Society and sponsored by Google UK, the award was established in memory of computer conservation pioneer Tony Sale, who rebuilt Colossus, the World War II code-breaking computer, and co-founded the Computer Conservation Society.

Presentation of £1000 cash and a trophy will be made in London on 17 November 2016.

This is the third Tony Sale Award, the first was won by German David Link for his computer art installation Loveletters, and the second jointly by the IBM 1401 Demo Lab, a restoration of one of the most significant machines in computer history by the Computer History Museum in California, and Z1 Architecture and Algorithms, a virtual reconstruction of the 1930s Konrad Zuse mechanical computer, by the Free University of Berlin.

Projects, which may cover hardware and/or software and represent any period in computing history, should normally have been completed in the past five years. Projects may be the result of the work of individuals or a team.

The closing date for nominations is 30 June 2016. A short entry form is available as a download on the Tony Sale Award website: **www.sale-award.org**

Hand-cranked iPhone

AMPware have launched the first mechanical-to-electrical energy smartphone case. Designed for the iPhone 6/6s, the hand-crank design powers up your depleted battery with a good old-fashioned mechanical energy source – you.

Users simply unfold the crank handle and spin. The handle is connected to a rare-earth magnet dynamo, which generates power to charge the phone. The designers claim five minutes of work will give you an hour of normal-use battery life and that it is 23-times more powerful than typical solar cells designed for phone charging – plus, it works at night. The AMPware Case provides backup talk/text time when you have no access to a socket and in an emergency could be a lifesaver, or perhaps more realistically, lets you make that all-important eBay bid before your battery expires from constant browser refreshing! More details available at: **http://getampware.com**

DIY induction heater

RM Cybernetics has launched a DIY induction heating kit for a very reasonable £35. Their new CRO-SM1 is an ultra-compact induction heater circuit and ZVS transformer driver designed for embedded applications. It is a type of collector resonance oscillator circuit, which will automatically drive reactive circuits at their resonant frequency – ideal for making a *DIY Induction Heater* or solid-state Tesla coil. You can read all about it – including the real and important health warnings – on their website at: **www.rmcybernetics.com/projects/DIY_Devices/diy-induction-heater.htm**

Rubik's Cube robot

Think you're good at solving the infamous cube puzzle? How about in under a second?! Jay Flatland and his friend Paul Rose have built a robot based on a Linux-powered PC, an Arduino, webcams and stepper motors that will solve a scrambled cube in around one second. You can see their robot in action at: **https://youtu.be/ixTddQQ2Hs4**

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TechnoTalk

Beware of bargains!

Mark Nelson

Electronic gadgets and components have never been cheaper in real terms. But is this really a bonanza or simply a cruel deception and a trap for the unwary? Mark Nelson sounds a note of caution.

IN THE 'BASIL THE RAT' EPISODE of *Fawlty Towers*, Basil asks: 'Can't we get you on *Mastermind*, Sybil? Next contestant – Sybil Fawlty from Torquay. Special subject – the bleedin' obvious.' So, it's equally obvious to just about every reader that the prices of electronic components and modules have never been so low as now.

Public service

Of course, I should qualify this assertion by adding the following qualifications: 'online', 'if you look in the right places' and 'if you're prepared to take a gamble'. Let me explain. I would not say I have noticed prices plummeting in the stores of our largest national chain of electronic wares and to be fair, I would not expect to. They have to pay eye-watering rents, high business rates and the wages of their staff. They also stay open until 8pm on weekdays and will not turn you away even if all you have come in for is a pack of 10kΩ resistors or a single DIN plug. They perform a public service by supplying vital parts just when you need them urgently.

Right, where do I mean by 'online'? Well, look on eBay for a start. You can type in the designation of just about any component and up will come a load of offerings, some from UK sellers and others from overseas (probably, mainly from China; we shall come back to China later). It may surprise you that Amazon is also good for components and modules nowadays; these are offered by Amazon's marketplace suppliers, and once again, many hail from China. Three other fruitful places to look are: **Banggood.com**, **Newfrog.com**, and probably the best of this trio, **AliExpress.com**. As far as I can tell, all three are based in China and generally they work like eBay does – you need to register first. However, nearly everything is offered at fixed prices, without the need to bid. Each website will offer to send you regular email alerts about special offers, which can be remarkably cheap.

Buying from China

I have to say I have had mixed experience here. You can save a fortune, as prices are far cheaper than from UK suppliers. Many of the sellers buy up job lots and have only limited numbers of the component you want. When it's gone, it's gone! I suspect that in many cases the dealers have no idea what they have bought and just want to sell it on as rapidly as possible. Occasionally, the parts never turn up, but if you buy through eBay, you will get a refund. On the customs declaration label many sellers under-declare and/or misdescribe the contents of the package, with the result that I have never been clobbered to pay VAT or customs duty. Items can take up to five weeks to arrive, although some arrive within ten days or less, sometimes from an 'aggregation depot' in Belgium or Germany. Some of the UK-based eBay sellers of Chinese goods don't actually hold stocks of the items over here; instead they get them from China by priority mail and forward them to you, so that you receive your goods a few days after you ordered them – weird and wonderful!

Cheap as...? If the silicon you are after is a crazy price then you may not get the right kind of chips.

Cheap and cheerful – or cheap and nasty?

It's pot luck really, and you take a chance every time you buy. Nearly all the parts I have bought from China have been fine, but occasionally the finish of the goods is a little, well, naff. But this applies equally to things you buy in Britain. One of my chums bought some red and black single-strand wire from what he delightfully calls 'the big blue high street store that sells electronics and toys'. He states; 'I think this wire must use polythene for insulation, as it melts at the merest sight of a soldering iron.' I too have had a few duds from that firm, specifically connectors with intensely shiny solder tags that you could not solder onto, however much Fluxite and heat you used. Scraping the tags didn't work, although actually filing off the plating did.

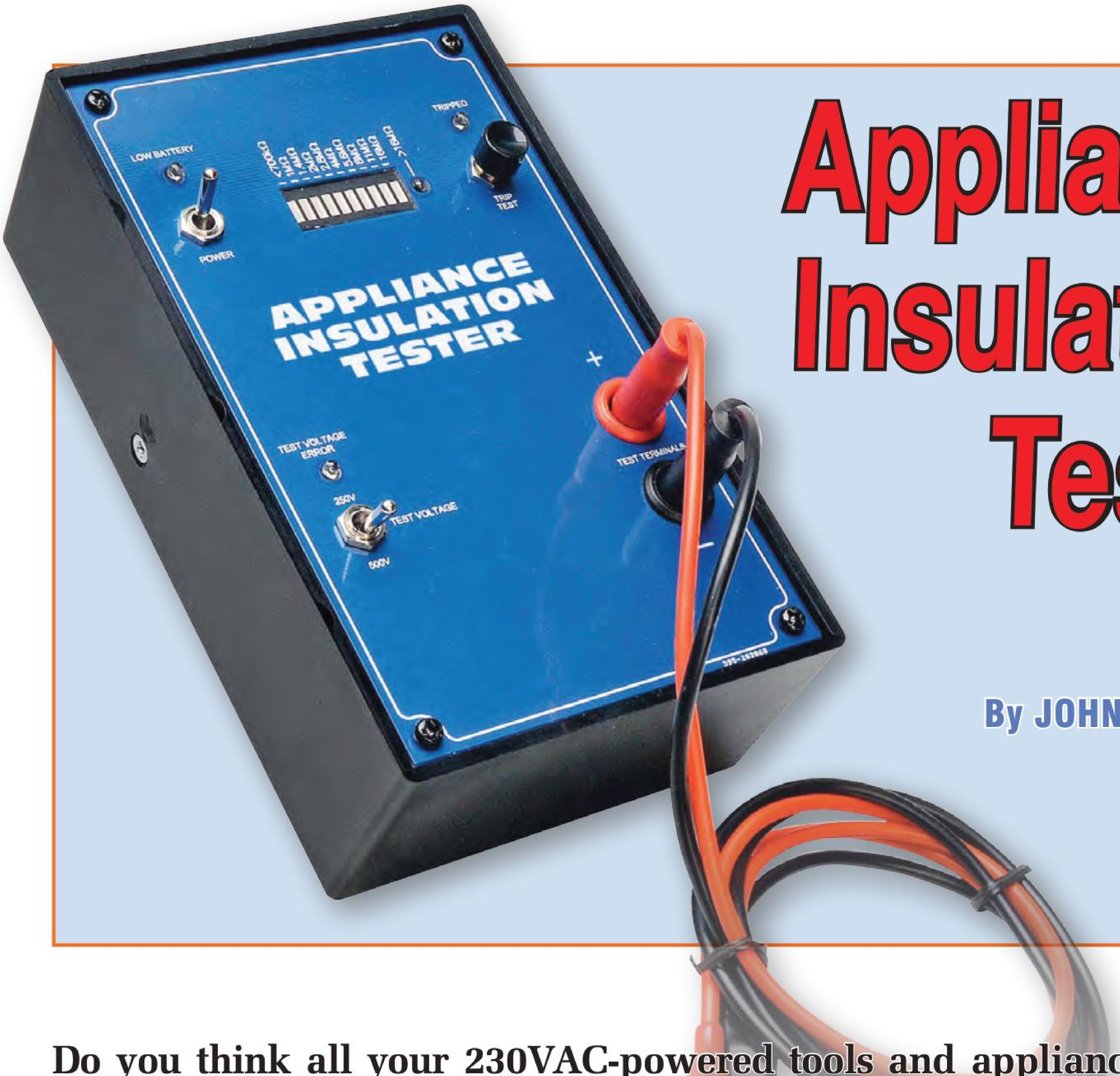
On street markets and at boot fairs things to avoid are dodgy batteries, power supplies, battery chargers and memory chips that are straightforward fakes. If they look too cheap to be true, they are probably not worth buying, *caveat emptor* or buyer beware! But what about your experiences, good or bad? Why not share them?

Wicked wire

Another bad bargain to be wary of is copper-covered steel (CCS) wire, now being sold on Amazon and elsewhere for indoor telephone wiring and Cat 5 data cabling. The conductors look exactly like pure copper and being soft-annealed, they feel only slightly harder than copper. It is heavier and less flexible than pure copper. The stuff costs substantially less than proper copper, but what about the performance? My informant tells me that the resistance, frequency response, cable lay (twisted pairs) and stiffness of CCS are likely to be far inferior, making it a false economy. He also sees a potential long-term problem of corrosion at the terminations, which is seldom a problem with copper. It's a disaster on all fronts and a false economy, he argues.

Follow on: the Amplidyne

Harking back to the mag amps discussed last month, our esteemed editor alerted me to the amplidyne. Wikipedia describes this as 'an electromechanical amplifier invented during World War Two by Ernst Alexanderson. It consists of an electric motor driving a DC generator. The signal to be amplified is applied to the generator's field winding, and its output voltage is an amplified copy of the field current. The amplidyne was used in industry in high power servo and control systems, to amplify low power control signals to control powerful electric motors, for example. It is now mostly obsolete.' Thanks ed!



Appliance Insulation Tester

By JOHN CLARKE

Do you think all your 230VAC-powered tools and appliances are safe because they are double-insulated? If so, you could be in for a rude shock – literally! Or do you think you are safe because your home (or workplace) is fitted with RCDs (residual current devices)? Again, you could still be at risk of a severe electric shock. The only way to be reasonably sure about appliance and power tool safety is to test them regularly. That is where our *Appliance Insulation Tester* is a crucial tool.

LET'S BE BLUNT: an RCD will not save you from electric shock if you use a faulty power tool or appliance. Nor will it necessarily save you from death. Have we got your full attention now?

An RCD (commonly called a safety switch) will switch off the 230VAC power if it detects an imbalance between the live and neutral currents in the appliance circuit. That imbalance could mean that current is flowing through your body rather than the mains wiring. At least 30mA of current needs to flow through your body for a typical RCD to switch off the power – but depending on the fault, the current could be a lot more than 30mA and the time before it is switched off could be up to 150 milliseconds. That's long enough to experience a very nasty electric shock and one which could possibly kill you.

Well hopefully, it would not kill you, but you could still be seriously injured. Say you get the shock while using the faulty tool and standing on an aluminium ladder. The shock could throw you off the ladder and you could be seriously injured or killed (again!). And anyway, how you do know the RCDs in your home are working properly? Have they been tested recently?

You can now see that appliances and power tools should be tested regularly. So we have produced our *Appliance Insulation Tester*, which checks whether the insulation resistance is adequate to protect you from serious shock on double-insulated or earthed appliances and power tools. It does this by applying 250V or 500V DC between mains live and neutral to the earth on the 3-pin plug of earthed appliances (Class 1 appliance) or to

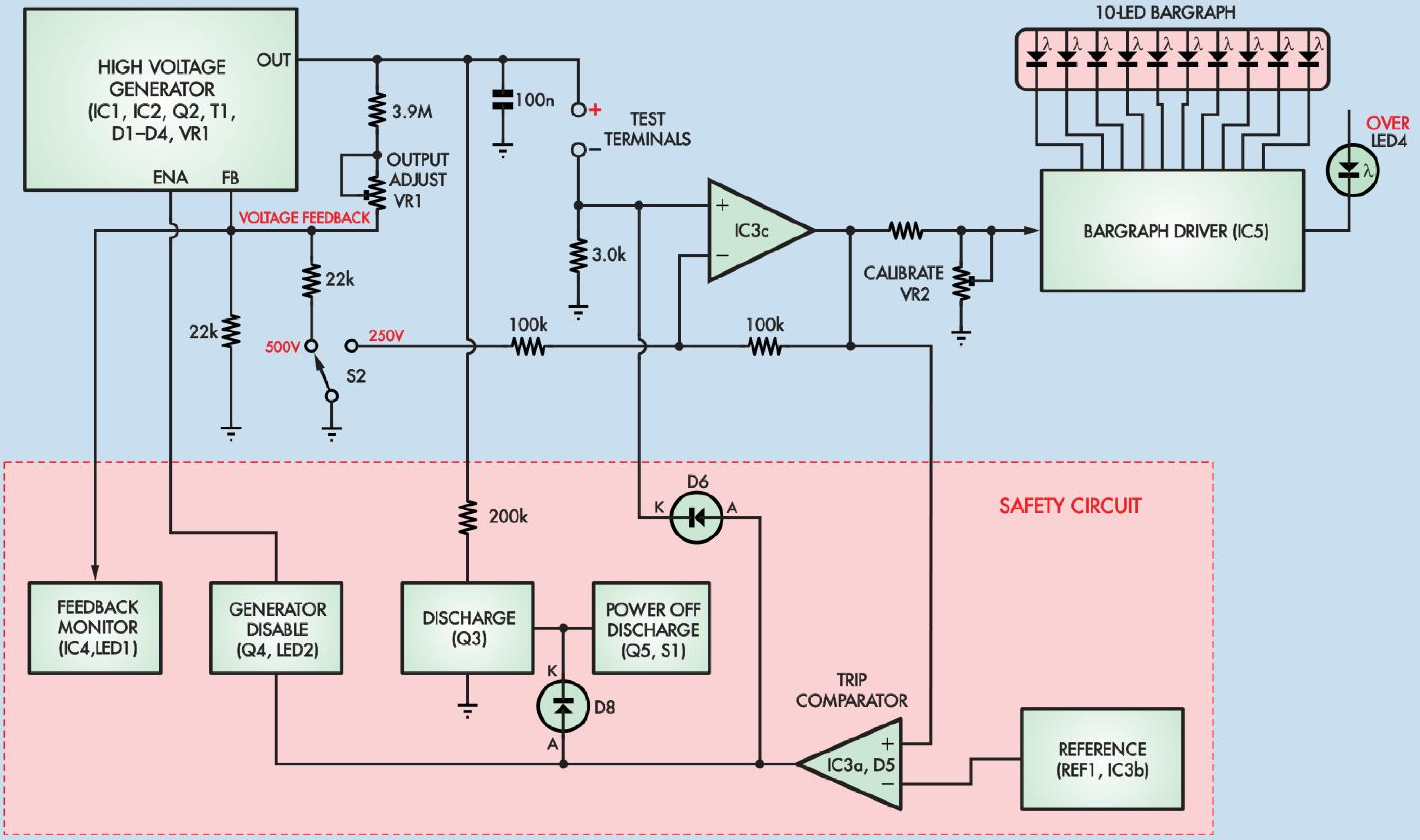


Fig.1: block diagram of the *Appliance Insulation Tester*; it uses a high-voltage generator (top, left) to produce either 250V or 500V DC, which is applied to the test terminals. The resulting leakage current through the appliance under test and the associated 3kΩ resistor is monitored by op amp IC3c, which then drives a 10-LED bargraph via IC5. IC3a monitors IC3c's output and shuts down the high-voltage generator via MOSFET Q4 if the voltage across the 3kΩ resistor exceeds 3V.

exposed metal on double-insulated appliances and then the insulation resistance is measured. In general, an insulation resistance (IR) below 1MΩ is deemed unsafe.

There are a couple of appliances where this 1MΩ value does not apply. The first is with a portable RCD that has a functional earth (ie, requires an earth for correct operation) and the second is for appliances which have mineral insulated metal sheath heating elements. Our *Appliance Insulation Tester* is **not** suitable for these devices.

Another instrument required

While our *Appliance Insulation Tester* will check most appliances, it does not apply 230VAC mains voltage and therefore cannot conduct an IR test on appliances that have a 'soft' or a non-mechanical power switch, such as in most appliances with remote controls (eg, DVD players and TV sets). These appliances can only be tested with an instrument that permits energising with the normal 230V supply voltage to measure the actual earth leakage current. We plan to feature an *Appliance Earth Leakage Tester* next month as a companion instrument.

Testing safely

We mentioned that the testing voltage used is 500V or 250V DC. 500V DC is the usual test voltage while 250V DC is used where an appliance has overvoltage protection. These voltages are high enough to give you a nasty shock if you come into contact with both the test probes, so we have incorporated three safety features.

The first is the use of shrouded banana sockets for the high voltage output terminals. Second, there is a 1mA (or 500µA depending on output voltage) trip current detector that shuts off the high voltage if this current is exceeded. So if you do make contact with both the test probes you will get an unpleasant 'tickle' instead of possibly a more severe electric shock.

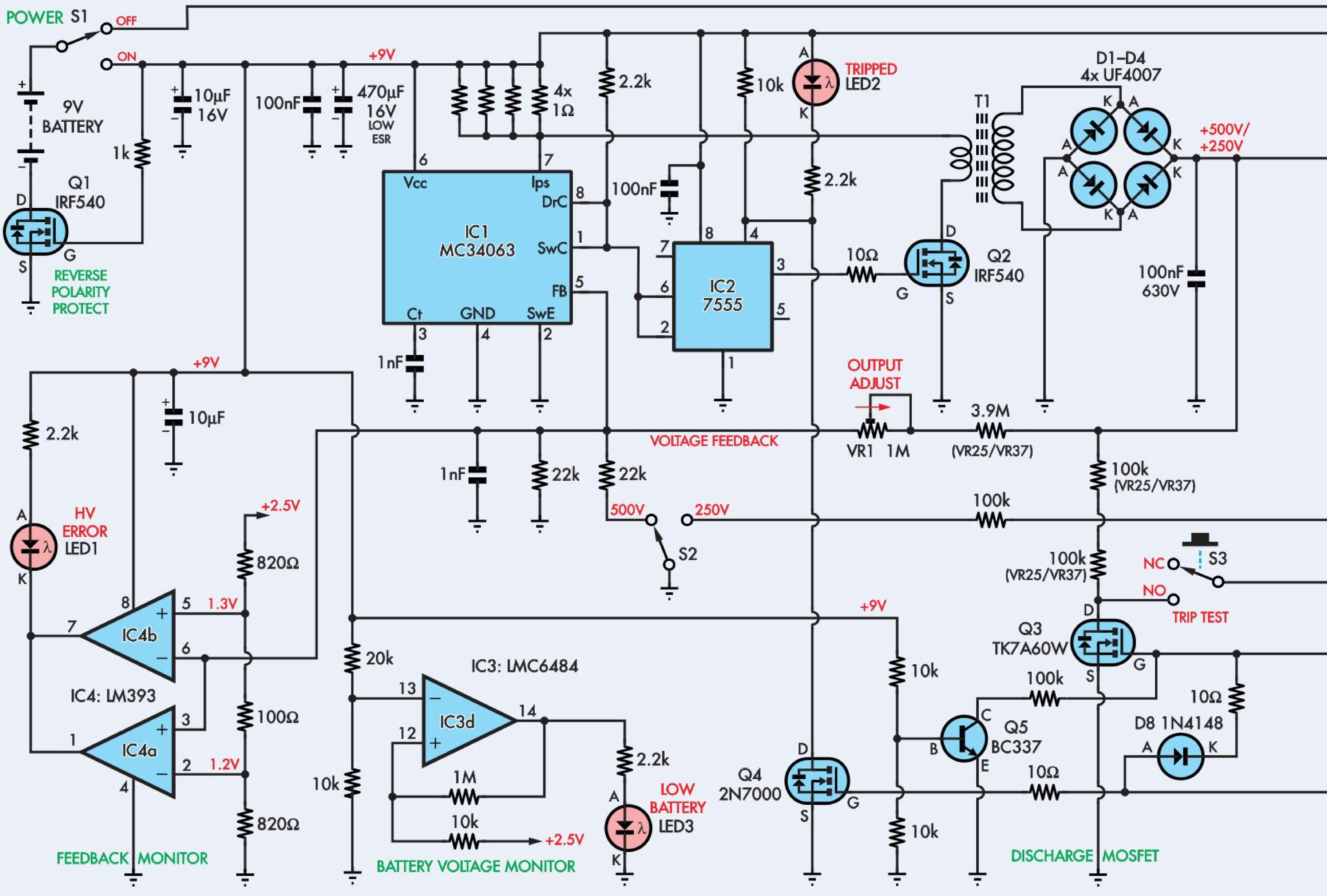
Also, the *Appliance Insulation Tester* has a Trip Test pushbutton which verifies that the unit will shut down if you make contact with the probes. It also lights an LED to indicate that it has been tripped. To restore operation, the unit has to be switched off and then on again.

Finally, a check LED is included to indicate if the high-voltage generator is not working correctly.

Simplified circuit

Fig.1 shows the simplified circuit arrangement of the *Appliance Insulation Tester*. It comprises a high-voltage generator that can be set to produce either 250V or 500V DC, with voltage feedback to maintain the required voltage with varying load. IC4 includes two comparators which detect if there is a fault in the high-voltage output. A high or low voltage is indicated with LED1 (HV Error).

The positive high voltage becomes the '+' test output, while the negative (–) test output is connected to the supply ground via a 3kΩ resistance. When the test terminals are connected to an appliance to test for insulation resistance, any leakage current will flow through this 3kΩ resistance and so develop a voltage. This voltage is monitored by IC3c, a high-input-impedance, low-input-current op amp.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ON
+9V
9V BATTERY
10µF 16V
100nF
470µF 16V LOW ESR
4x 1Ω
2.2k
10k
TRIPPED LED2
A
K
D1–D4 4x UF4007
T1
+500V/ +250V
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Q4 2N7000
10Ω
10k
10k
820Ω
+2.5V
FEEDBACK MONITOR
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DISCHARGE MOSFET

APPLIANCE INSULATION TESTER

Fig.2: the circuit of the *Appliance Insulation Tester*; the high-voltage generator consists of an MC34063 DC-DC converter (IC1), a 7555 CMOS timer (IC2), MOSFET Q2, step-up transformer T1 and bridge rectifier D1-D4. IC3c monitors the leakage current through the two series 1.5kΩ resistors and drives IC5, while IC3a is the trip comparator for the safety circuit.

IC3c operates as a unity-gain buffer for the 500V setting or with a gain of two when 250V is selected. So, for example, a 1MΩ leakage resistance between the test terminals with a 500V DC test voltage would produce a current of 500µA. This gives 1.5V across the 3kΩ resistance and thus 1.5V at IC3c's output.

For 250V DC, the current with the same 1MΩ leakage resistance would give 250µA and there would be 750mV across the 3kΩ resistance. However, we still get 1.5V at IC3c's output because it now operates with a gain of two.

The pin 8 output of IC3c is attenuated and fed to IC5, an LM3915 dot/bar display driver (used in dot mode) and a 10-LED bargraph display. The display shows resistance in 10 3dB steps: <707kΩ, 1MΩ, 1.4MΩ, 2MΩ, 2.8MΩ, 4MΩ, 5.6MΩ, 8MΩ, 11MΩ and 16MΩ. A separate LED lights for resistance values of more than 16MΩ.

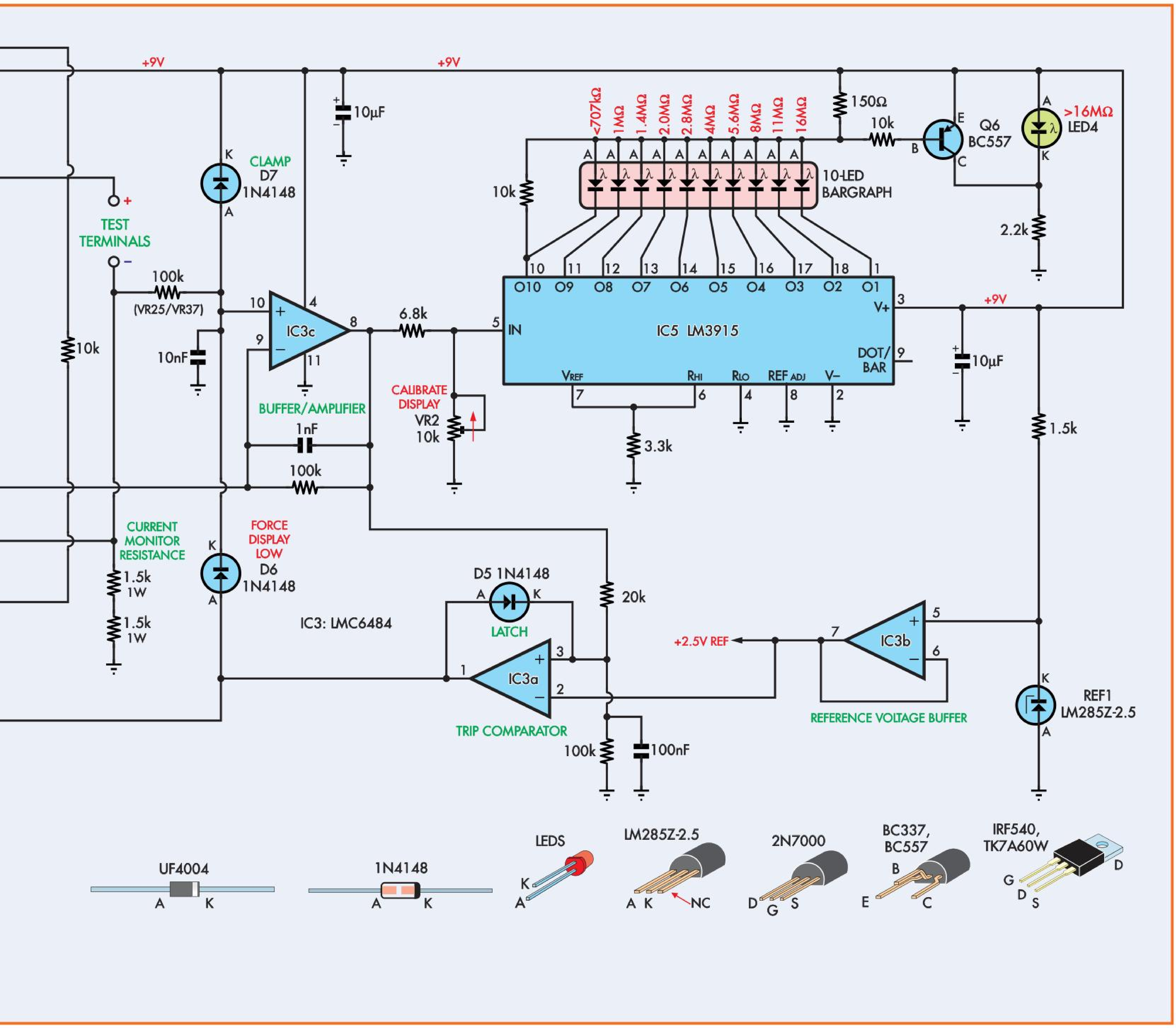
Op amp IC3a compares the output of IC3c with a 2.5V reference voltage set by IC3b. If the voltage across the 3kΩ resistance reaches 3V, IC3a's output goes high to turn on MOSFET Q4 and disable the high-voltage generator. At the same time, MOSFET Q3 discharges the high-voltage generator's 100nF output capacitor via a 200kΩ resistance and the display will show a low-ohm (<707kΩ) reading. In addition, LED2 indicates that the high-voltage generator has been disabled.

Finally, since the high-voltage output will be zero, the feedback monitor will turn on the high-voltage error indicator, LED1.

As already noted, to restore operation, the unit has to be switched off and then on again. Note that if the unit is switched off, MOSFET Q3 discharges the high-voltage capacitor, under the control of transistor Q5, which monitors the on/off switch.

Full circuit

The full circuit is shown in Fig.2. The high-voltage generator comprises an MC34063 DC-DC converter (IC1), a 7555 CMOS timer (IC2), MOSFET Q2 and transformer T1. If this circuit did


+9V
+9V
10µF
CLAMP
D7
1N4148
K
A
TEST TERMINALS
+
–
100k
(VR25/VR37)
10k
10nF
10
9
4
8
11
IC3c
BUFFER/AMPLIFIER
1nF
100k
6.8k
CALIBRATE DISPLAY
VR2
10k
<707kΩ
1MΩ
1.4MΩ
2.0MΩ
2.8MΩ
4MΩ
5.6MΩ
8MΩ
11MΩ
16MΩ
10k
10-LED BARGRAPH
10 11 12 13 14 15 16 17 18 1
O10 O9 O8 O7 O6 O5 O4 O3 O2 O1
IN
5
IC5 LM3915
V+
3
DOT/BAR
9
VREF
RHI
RLO
REF ADJ
V–
7 6 4 8 2
3.3k
150Ω
10k
Q6
BC557
E
B
C
>16MΩ
LED4
2.2k
+9V
10µF
1.5k
CURRENT MONITOR RESISTANCE
1.5k 1W
1.5k 1W
FORCE DISPLAY LOW
D6
1N4148
IC3: LMC6484
D5 1N4148
LATCH
20k
1
2
3
IC3a
TRIP COMPARATOR
100k
100nF
+2.5V REF
7
IC3b
5
6
REFERENCE VOLTAGE BUFFER
REF1
LM285Z-2.5
UF4004
A K
1N4148
A K
LEDS
K A
LM285Z-2.5
A K NC
2N7000
D G S
BC337, BC557
B
E C
IRF540, TK7A60W
G D S
D

not have the trip current protection feature, IC1 and IC2 could have been used in a slightly simpler configuration, with the 7555 used as a rail-to-rail MOSFET gate driver and with no gating function via Q4.

IC1c's oscillator runs at a nominal 30kHz, as set by the 1nF capacitor at pin 3. IC1's output pins (1 and 8) are open-collector transistors that are pulled up to the 9V supply by a 2.2kΩ resistor. The 30kHz output signal is coupled to IC2, a 7555 which is mainly used as an inverting buffer/gate which drives MOSFET Q2.

When Q2 is switched on, current flows through the primary winding of transformer T1 until it peaks at about

Main Features

- Displays insulation resistance in 10 steps from 707kΩ to 16MΩ with acceptable resistance in green and unacceptable resistance in orange and red
- 500V DC and 250V DC test voltages
- 1mA/500µA over-current trip for safety
- Over-current trip test and trip indicator
- Low battery indicator
- High-voltage fault indicator
- High voltage discharges to safe levels at power off and over-current trip out
- Not suitable for portable residual current devices that incorporate a functional earth
- Not suitable for mineral insulated metal-sheathed heating elements

Appliance Insulation Tester: Parts List

- 1 double-sided PCB, available from the *EPE PCB Service*, coded 04103151, 86 × 133mm
- 1 front panel PCB, available from the *EPE PCB Service*, coded 04103152, 90 × 151mm
- 1 UB1 plastic utility box 158 × 95 × 53mm
- 1 ferrite pot core and bobbin set (Jaycar LF-1060, LF-1062; Altronics L 5300, L 5305) (T1)
- 1 pot core spacer eg 0.25mm cardboard 11mm OD or similar (see text)
- 1 9V battery clip lead
- 1 9V battery
- 1 9V battery U-shaped holder
- 1 20-pin wire wrap SIL socket strip for LED bargraph
- 2 SPDT toggle switches, PCB-mount (S1,S2)
- 1 SPDT pushbutton PCB-mount switch (S3)
- 1 red safety banana socket
- 1 black safety banana socket
- 1 shrouded safety multimeter test lead set (Altronics P 0404A, Jaycar WT-5325)
- 3 M3 tapped 9mm nylon spacers
- 3 M3 tapped 6mm nylon spacers
- 3 M3 × 12mm screws
- 3 M3 × 5mm screws
- 1 M3 × 10mm countersink screw
- 1 M3 × 25mm nylon screw
- 8 M3 nylon washers
- 2 M3 nuts
- 1 6.5m length of 0.25mm-dia. enamelled copper wire
- 1 700mm length of 0.5mm-dia. enamelled copper wire
- 1 40mm length of 230VAC rated red wire
- 1 40mm length of 230VAC rated black wire
- 3 PC stakes
- 1 1MΩ multiturn trimpot (VR1)
- 1 10kΩ multiturn trimpot (VR2)

Semiconductors

- 1 MC34063AP1 DC-DC converter (IC1)
- 1 7555 CMOS timer (IC2)
- 1 LMC6484AIN quad CMOS op amp (IC3)
- 1 LM393N dual comparator (IC4)
- 1 LM3915N dot/bar display driver (IC5)
- 1 10-LED green/yellow/red LED bar
- 2 IRF540 100V 33A N Channel MOSFETs (Q1,Q2)
- 1 600V low gate threshold N-channel MOSFET (Q3) (Toshiba TK7A60W or equivalent) (RS Components Cat. 799-5201)
- 1 2N7000 MOSFET (Q4)
- 1 BC337 NPN transistor (Q5)
- 1 BC557 PNP transistor (Q6)
- 1 LM285Z 2.5V reference (REF1)
- 4 UF4007 1000V 1A fast diodes (D1-D4)
- 4 1N4148 diodes (D5-D8)
- 3 3mm red high brightness LEDs (LED1-LED3)
- 1 3mm green high brightness LED (LED4)

Capacitors

- 1 470μF 16V low ESR electrolytic
- 4 10μF 16V PC electrolytic
- 3 100nF MKT polyester
- 1 100nF 630V metallised polyester
- 1 10nF MKT polyester
- 3 1nF MKT polyester

Resistors (0.25W, 1%)

- 1 3.9MΩ VR37/VR25 (3500V DC or 1600V DC)
- 1 1MΩ VR37/VR25 (for calibration) (3500V DC or 1600V DC)
- 3 100kΩ VR37/VR25 (3500V DC or 1600V DC)
- 1 1MΩ
- 4 100kΩ
- 2 22kΩ
- 2 20kΩ
- 8 10kΩ
- 1 6.8kΩ
- 1 3.3kΩ
- 5 2.2kΩ
- 1 1.5kΩ
- 2 1.5kΩ 1W
- 1 1kΩ
- 2 820Ω
- 1 150Ω
- 1 100Ω
- 3 10Ω
- 4 1Ω 5%

1.2A. This current flows through the four paralleled 1Ω resistors between pins 6 and 7 of IC1 and when it reaches 1.2A, IC1 stops its oscillator and MOSFET Q2 is switched off. Thus, the magnetic field in the transformer core collapses, producing high voltage in the primary winding. The secondary winding steps up the voltage and feeds a bridge rectifier comprising diodes D1-D4 to produce a 500V (or 250V) DC supply and this is filtered with a 100nF 630V DC capacitor.

Note that a single diode could have been used instead of the bridge rectifier. However, a single diode rectifier would require the transformer windings to be correctly phased and this can be a problem for constructors winding their own transformers. Using a bridge rectifier makes transformer winding and termination easier.

Since the load on the high-voltage supply can vary, we have voltage feedback to pin 5 of IC1 via a 3.9MΩ resistor and 100kΩ trimpot VR1, together with a 22kΩ resistor at pin 5 of IC1 to ground. VR1 is adjusted to provide an output of 250V DC. An extra 22kΩ resistor is switched via S2 to provide the 500V setting.

Either way, the feedback divider reduces the high voltage to a nominal 1.25V at pin 5 and this is compared against an internal 1.25V reference in IC1. If the output voltage drops, the duty cycle of the output waveform from pins 1 and 8 is increased to compensate (and vice versa).

Note that the 3.9MΩ feedback resistor is a VR37 or VR25 type, rated at 3500V DC or 1600V DC, respectively.

Note also that IC2 has its pin 4 reset pin connected to other parts of the circuitry. This is used to shut down the high-voltage generation when required. Under normal operation, pin 4 is pulled high via a 10kΩ resistor to allow IC2 to operate.

Voltage fault indication

As mentioned above, the circuit has voltage fault indication and this comprises IC4, an LM393 configured as a 'window' comparator. It drives LED1 when the voltage feedback signal fed to pin 5 of IC1 is outside the limits set at its pins 5 and 2 (of IC4). Normally, with feedback voltage in the range of 1.2-1.3V, the paralleled open-collector outputs of IC4 at pins 1 and 7 will remain high and LED1 will be unlit.

If the feedback voltage drops below 1.2V, pin 1 of IC4a will go low to light LED1. Similarly, if the feedback voltage goes above 1.3V, pin 7 of IC4b will go low instead to again turn on LED1. So if LED1 lights, it indicates that the DC-DC converter is not producing the correct high voltage.

It is not a completely foolproof check of output voltage because if one of the feedback resistors should fail or change its value, the feedback voltage could be correct, but the output voltage will not. However, it is still a useful indicator as it will light up when the DC-DC converter is shut down or if the output cannot provide sufficient voltage under load. Of course, test voltages can be periodically checked with a multimeter.

Output terminals

As can be seen on the circuit, the positive output of the high-voltage generator connects directly to the positive (red) test terminal, while the negative test terminal is connected to circuit ground via two 1.5kΩ 1W resistors connected in series. These provide a means of monitoring the load current for the *Appliance Insulation Tester*.

IC3c monitors the voltage across the resulting 3kΩ resistance via a 100kΩ resistor. This 100kΩ resistor protects the op amp's input should one of the 1.5kΩ resistors go open circuit and allows the full 250V or 500V to be applied. Diode D7 clamps the input to just over the +9V supply.

IC3c amplifies the voltage across the 3kΩ resistance by a factor of two when switch S2 is in the 250V position. In the 500V setting, S2 disconnects the associated 100kΩ resistor from ground and connects another 22kΩ resistor between pin 5 of IC1 and ground. As well as doubling the output from the high-voltage generator, it converts IC3c to a unity-gain voltage follower. So either way, the following LED display circuitry involving IC5 gets the correct signal range which is fed via a 6.8kΩ resistor and 10kΩ trimpot VR2.

IC5 is an LM3915 logarithmic dot/bar driver and this drives the 10-LED display. An internal 1.25V reference at pin 7 sets the full-scale input voltage. IC5 is set in dot mode, meaning that only one LED in the 10-LED bargraph is driven at any one time.

For our circuit, full scale is when the LED at pin 10 is lit and this is labelled 707kΩ. Other LEDs show 1MΩ, 1.4MΩ,... as mentioned above. If any of the 10 LEDs in the bargraph is lit, the resulting LED current through the 150Ω resistor from the +9V rail will produce a voltage to switch on transistor Q6 and it shunts LED4 so it cannot light.

If all the bargraph LEDs are off, Q6 will be off and LED4 will light, indicating that the load across the tester's terminals is more than 16MΩ. So in practice, with nothing across the test terminals, LED4 will be lit.

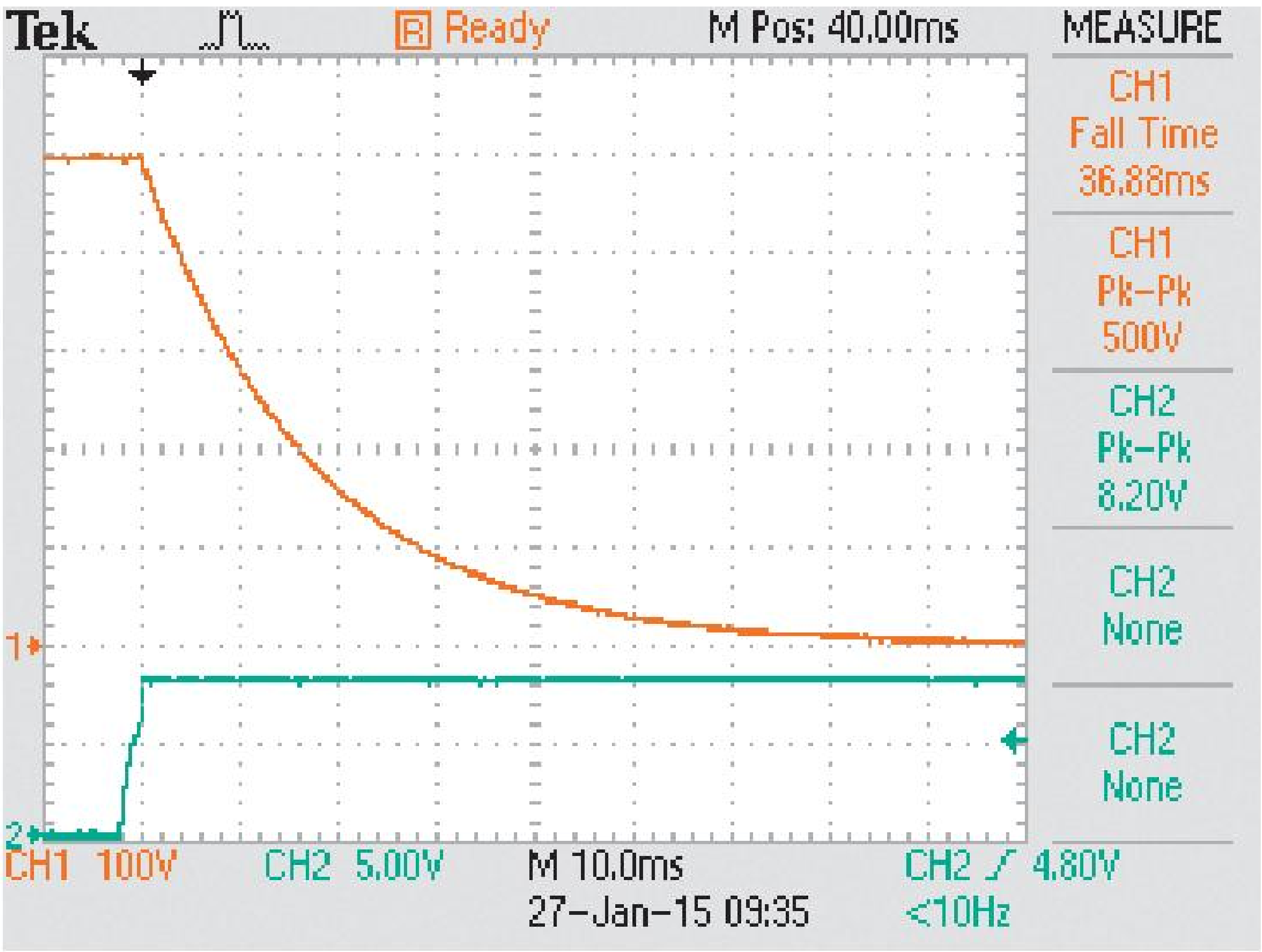


Fig.3: this scope grab shows the action of the trip circuit when the load current exceeds 1mA (for the 500V setting). The green trace shows the voltage across the 3kΩ monitor resistance and the orange trace shows the resulting exponential drop in the high voltage in less than 40ms.

Over-current trip

As noted above, the trip circuit shuts down the high voltage if the leakage current exceeds 1mA in the 500V setting and 500µA for the 250V setting.

The over-current detection circuitry comprises op amps IC3a, IC3b, Q3 and Q4 and REF1. REF1 is an LM285 2.5V reference and IC3b buffers it and feeds the inverting input of IC3a at pin 2. IC3a's non-inverting input at pin 3 monitors the output of IC3c via a voltage divider comprising a 20kΩ and 100kΩ resistor.

IC3a is connected as a comparator. If IC3c's output goes above 3V, the load current through the two 1.5kΩ current-monitoring resistors will evidently be above 1mA (for the 500V DC setting). So with a voltage just above 3V from IC3c, IC3a's output goes high and D5 pulls pin 3 up even further to ensure IC3a then stays latched. IC3a's high output then switches on MOSFET Q4 and it pulls down pin 4 (the reset input) of IC2. IC2 now acts as a gate and shuts off the drive to MOSFET Q2 to kill the output of the high-voltage generator. At the same time, LED2 lights to indicate that the high voltage is off and the over-current circuit has tripped.

In addition, diode D8 drives the gate of MOSFET Q3 to discharge the 100nF high-voltage supply capacitor via two 100kΩ resistors. And finally, diode D6 drives the input of IC3c to well over 3V so that the LED display will show a low reading, ie, '<700kΩ'.

As mentioned previously, the high-voltage error LED (LED1) will also light to indicate that the high voltage has shut down. To return to normal operation, the *Appliance Insulation Tester* is simply switched off and on again.

Pushbutton switch S3 connects the two 100kΩ VR25/VR37 resistors on the positive high-voltage supply to the negative test terminal. The resulting current through the 3kΩ monitor resistance causes the circuit to trip out as described earlier. The trip test current is 2.5mA at 500V and 1.25mA at 250V. These test currents are more than twice the rated trip current, but will at least verify that the trip current circuit will work.

If you are unfortunate enough to get a shock from this *Appliance Insulation Tester*, it shuts down the high voltage to safe levels within 40ms (much faster

Specifications

Power: 9V at 25mA for a 500V output, 18mA for 250V (with >16MΩ leakage resistance), 110mA at 600kΩ leakage and 500V test voltage

Low-voltage indication: 7.5V. Circuit operates down to 5V

Output voltage: 500V, 250V with <1% variation from no load to 1mA trip point

Leakage trip current: 1mA at 500V, 500µA at 250V

Trip test current: 2.5mA at 500V, 1.25mA at 250V

High-voltage discharge rate: the 500V output drops below 50V in 40ms

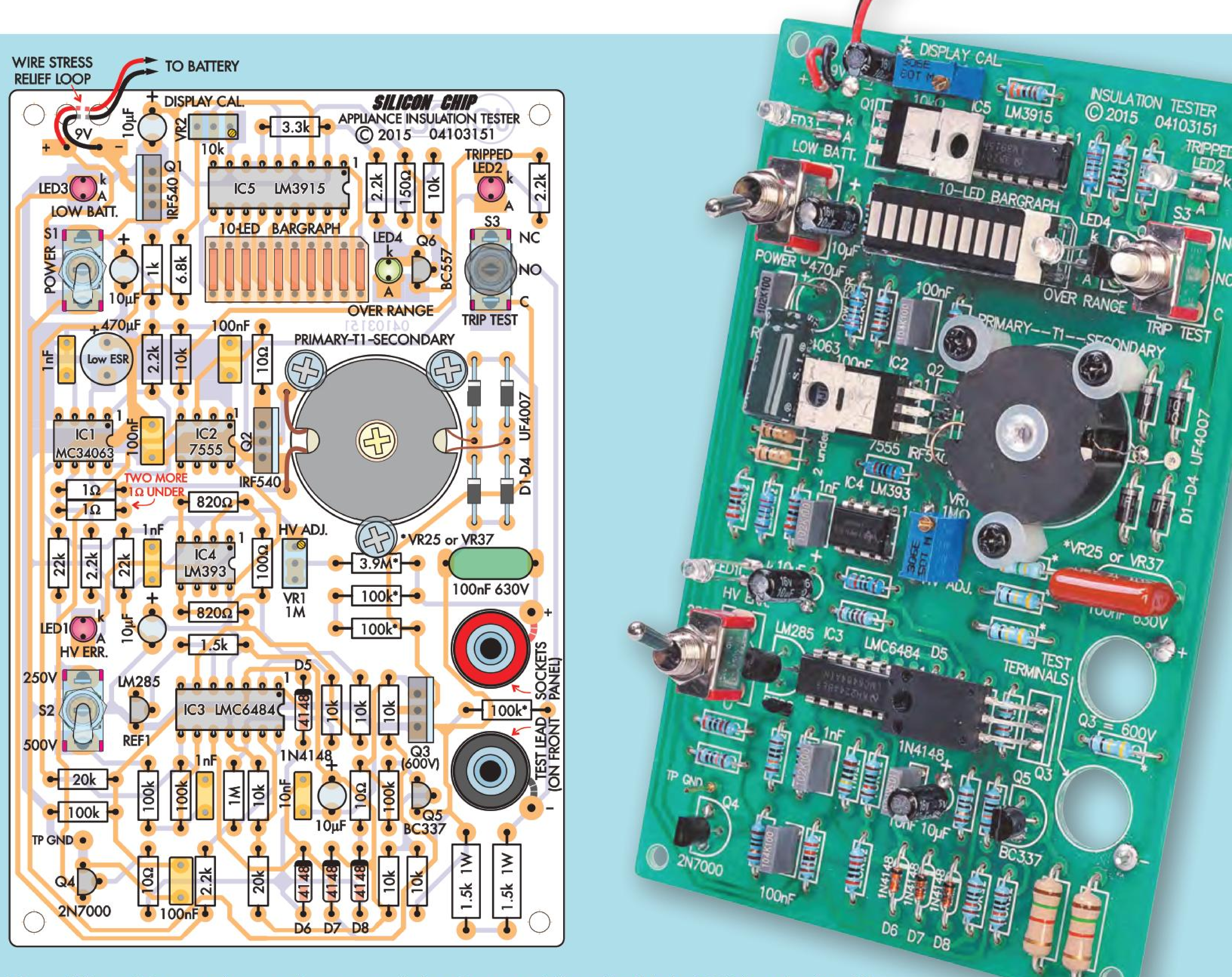

WIRE STRESS RELIEF LOOP
TO BATTERY
SILICON CHIP
APPLIANCE INSULATION TESTER
© 2015 04103151
9V
10µF
DISPLAY CAL.
VR2
10k
3.3k
IRF540 Q1
IC5 LM3915
2.2k
150Ω
10k
TRIPPED LED2
2.2k
LED3
LOW BATT.
S1
POWER
1k
6.8k
10-LED BARGRAPH
LED4
Q6
BC557
S3
NC
NO
C
TRIP TEST
OVER RANGE
470µF
100nF
1nF
Low ESR
2.2k
10k
10Ω
PRIMARY–T1–SECONDARY
IC1 MC34063
IC2 7555
Q2
IRF540
UF4007
D1-D4
1Ω
TWO MORE 1Ω UNDER
820Ω
HV ADJ.
*VR25 or VR37
22k
2.2k
22k
IC4 LM393
100Ω
3.9M*
100k*
100nF 630V
VR1 1M
LED1
HV ERR.
1.5k
250V
S2
500V
LM285
REF1
IC3 LMC6484
D5
4148
1N4148
Q3 (600V)
SOCKETS (ON FRONT PANEL)
TEST LEAD (ON FRONT PANEL)
20k
100k
1M
10µF
Q5 BC337
TP GND
Q4
2N7000
100nF
20k
D6 D7 D8
1.5k 1W
TEST TERMINALS
Q3 = 600V

Fig.4: follow this parts layout diagram and the photo at right to build the PCB but don't solder the LEDs or connect the insulated banana sockets until after the front panel PCB is attached (see text). Fig.5 and Fig.6 on the following pages show the transformer winding details.

than any RCD is supposed to disconnect the 230VAC mains supply in the event of a fault or shock).

9V battery

A 9V battery powers the circuit and it is connected via switch S1 in the positive lead. MOSFET Q1 is connected in the negative lead to the battery and provides protection against reversed polarity (ie, when you connect the battery the wrong way around). If the polarity is correct, the internal diode in Q1 will conduct and Q1's gate will be driven to 9V via a 1kΩ resistor to switch it on. If the 9V is reversed, Q1's internal diode will be reverse biased and the MOSFET will remain off.

A low-battery indicator is provided by op amp IC3d, connected as a comparator. It compares the 2.5V from REF1 with a sample of the battery voltage fed via the 20kΩ and 10kΩ resistors on pin 13. This will cause the comparator to switch its output to turn on LED3 for battery voltages of less than 7.5V. The 1MΩ resistor between pins 14 and 13 provides 135mV of hysteresis to stop any flickering of the LED. Note that the circuit will continue to operate down to about 5V.

Note also that we have not provided a separate power indicator LED since either the LED bargraph or LED4 will light whenever power is on.

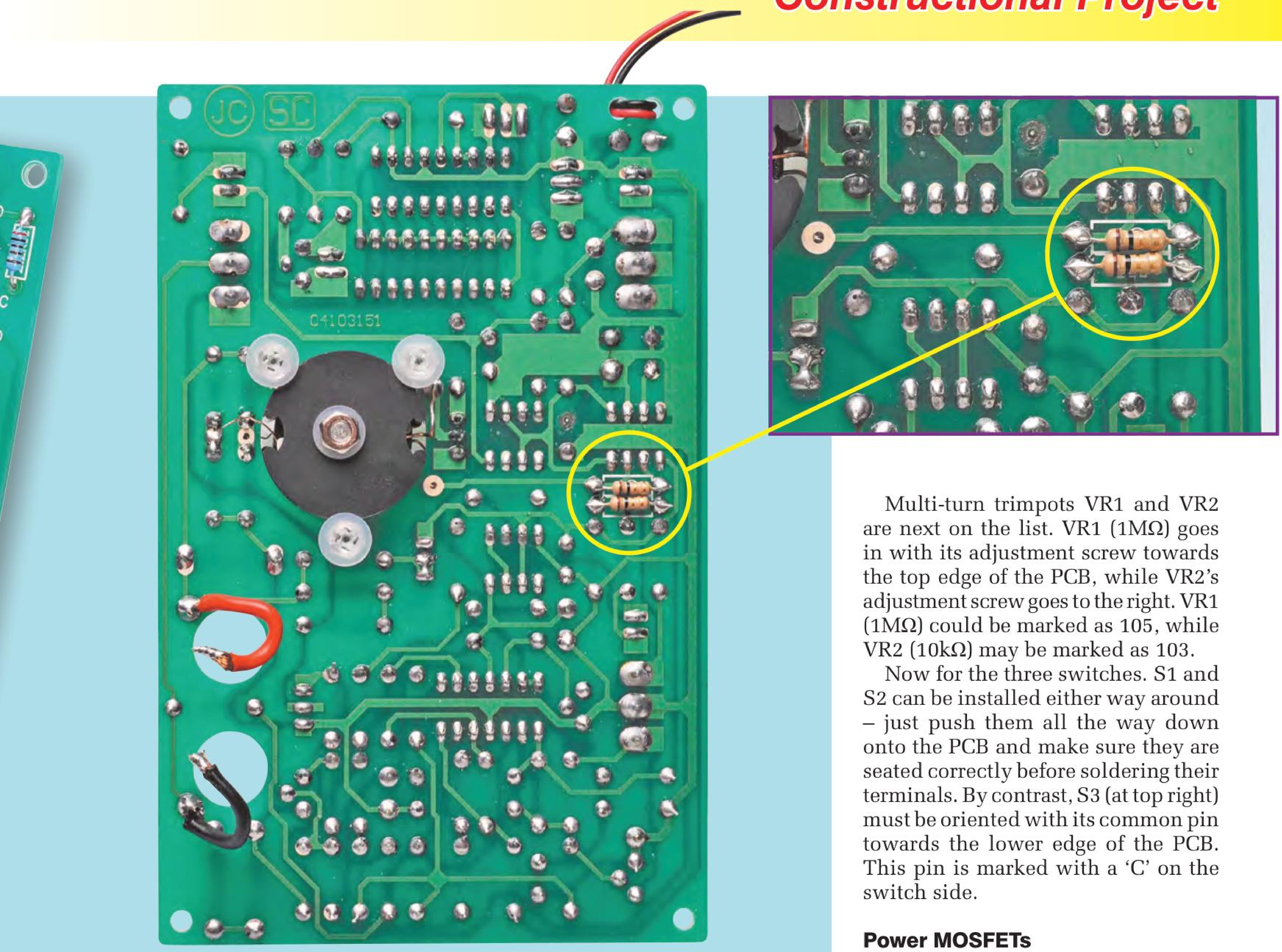
Assembly

The assembly is straightforward, with all parts installed on a double-sided PCB coded 04103151 and measuring 86 × 133mm which is available from the *EPE PCB Service*. A second PCB, also available from the *EPE PCB Service,* (coded 04103152, 90 × 151mm) is used as the front panel and this replaces the lid of the UB1 plastic utility box that's used to house the unit.

The two PCBs can be obtained either as part of a complete kit (ie, from parts retailers) or can be purchased as separate parts by visiting our secure online shop at: **www.epemag.com**.

Fig.4 shows the parts layout on the main PCB. Begin by installing the resistors and diodes, taking care to ensure that the latter are correctly oriented.

Two 1Ω resistors must be installed on the underside of the PCB. These are mounted directly under the two 1Ω resistors (located adjacent to IC1) and



The primary and secondary leads that emerge from the bottom of the transformer are soldered directly to their respective pads on the underside of the PCB. Note that two 1Ω resistors (circled) are also soldered to the underside of the PCB. These go directly under the two 1Ω resistors on the top of the PCB and are soldered directly to their solder pads, so that all four resistors are in parallel.

are installed in parallel with these two resistors. It's just a matter of soldering their leads directly to the pigtails of the top resistors.

Note that VR25 or VR37 resistors must be used in the positions marked with an asterisk (*). In addition, two different diode types are used – 1N4148 and UF4007. Be sure to install the UF4007 diodes adjacent to T1.

Once the resistors are in, install the three PC stakes. These are used for the positive and negative terminals adjacent to the test lead sockets and for the TP GND terminal (near Q4 at bottom left).

The ICs can now be installed. Make sure that the correct IC goes in each position and that it is oriented as shown on Fig.4. IC1, IC2 and IC4 are all 8-pin devices, so be careful not to get them mixed up.

Follow with the capacitors, taking care to install the electrolytics with the correct polarity. Note that the 470µF capacitor (near power switch S1) must be a low-ESR type. Note also that the top of each electrolytic capacitor must be no more than 15mm above the PCB, to allow clearance for the front panel PCB. It may be necessary to mount the 470µF low-ESR capacitor on its side to meet this requirement, as shown in the photos.

Transistors Q5 and Q6 and MOSFET Q4 can now go in. Q5 is a BC337 NPN type while Q6 is a BC557 PNP type, so don't get them mixed up. The LM285Z (REF1) should now be installed – it goes in to the left of IC3.

Multi-turn trimpots VR1 and VR2 are next on the list. VR1 (1MΩ) goes in with its adjustment screw towards the top edge of the PCB, while VR2's adjustment screw goes to the right. VR1 (1MΩ) could be marked as 105, while VR2 (10kΩ) may be marked as 103.

Now for the three switches. S1 and S2 can be installed either way around – just push them all the way down onto the PCB and make sure they are seated correctly before soldering their terminals. By contrast, S3 (at top right) must be oriented with its common pin towards the lower edge of the PCB. This pin is marked with a 'C' on the switch side.

Power MOSFETs

As shown in the photos, MOSFETs Q1-Q3 must be mounted horizontally, with their leads bent down through 90° to go into their respective PCB holes (this is necessary so that they don't foul the front panel PCB). Q1 and Q2 are both IRF540 types, while Q3 is a TK7A60W type (or equivalent).

Begin by soldering these MOSFETs in at full lead length, taking care to ensure that each is oriented correctly (Q1 and Q2 face in opposite directions). That done, grip the leads of each device in turn using needle-nose pliers and bend it over so that its body sits horizontally above the PCB.

Note that if Q3 has a metal tab, it should be covered with heatshrink tubing as the tab will have a high voltage on it. The specified TK7A60W has a plastic insulated tab and so does not require heatshrink insulation.

Installing the LED bargraph

The LED bargraph is mounted using a 20-way wire-wrap socket strip. First, break the socket strip into two 10-way strips and plug these into the bargraph

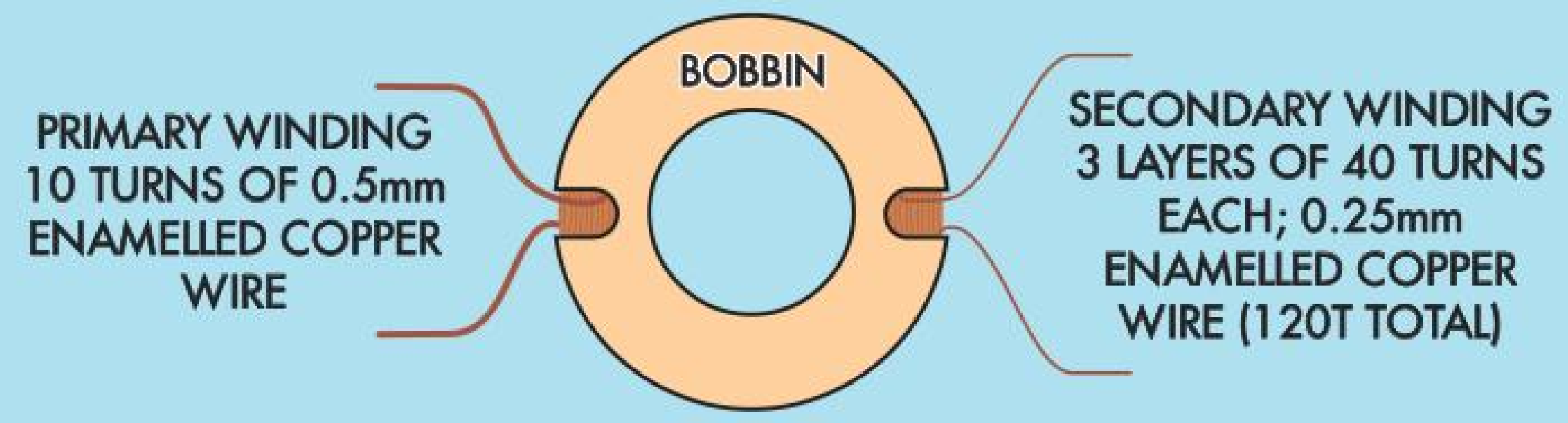
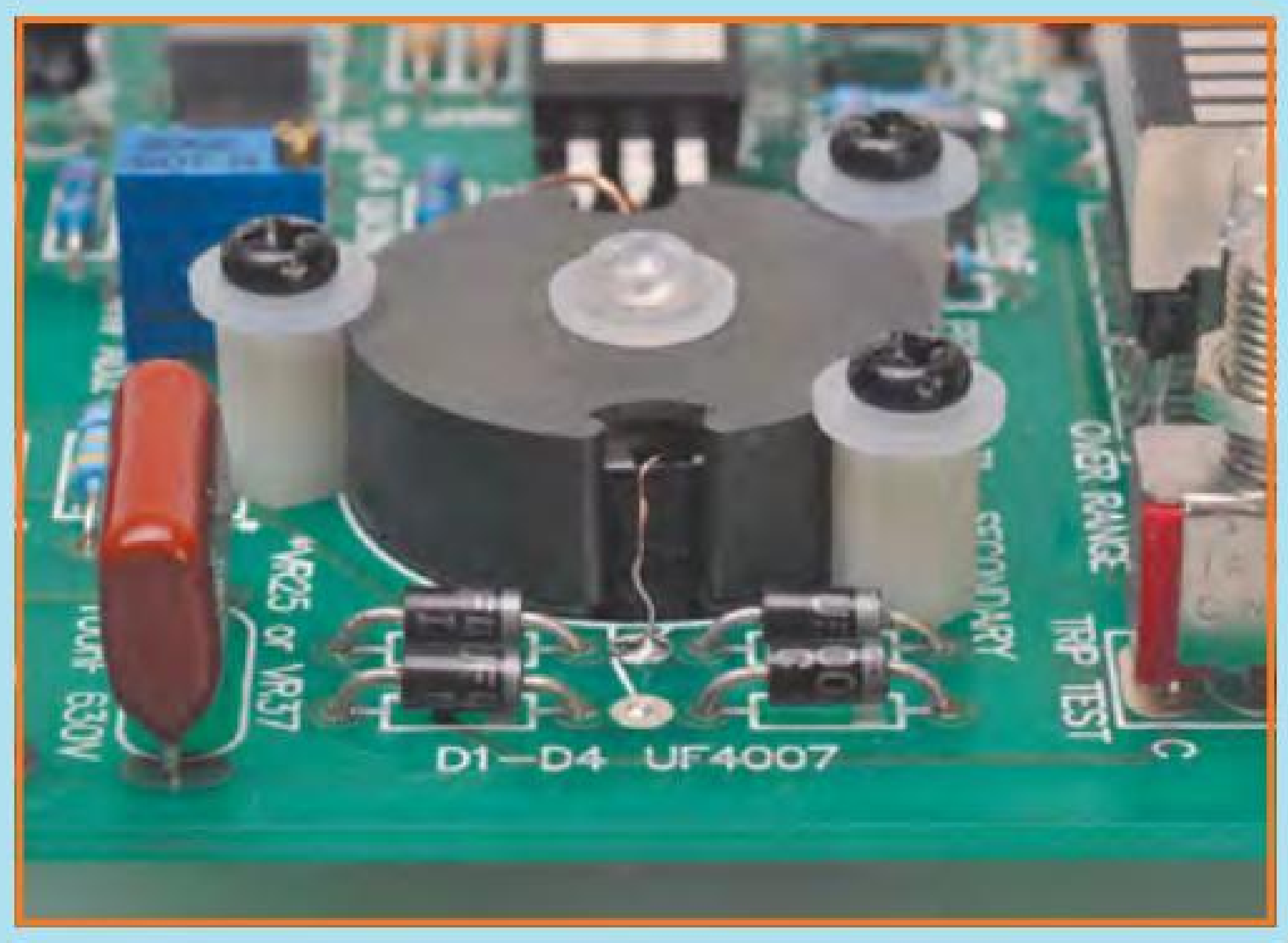
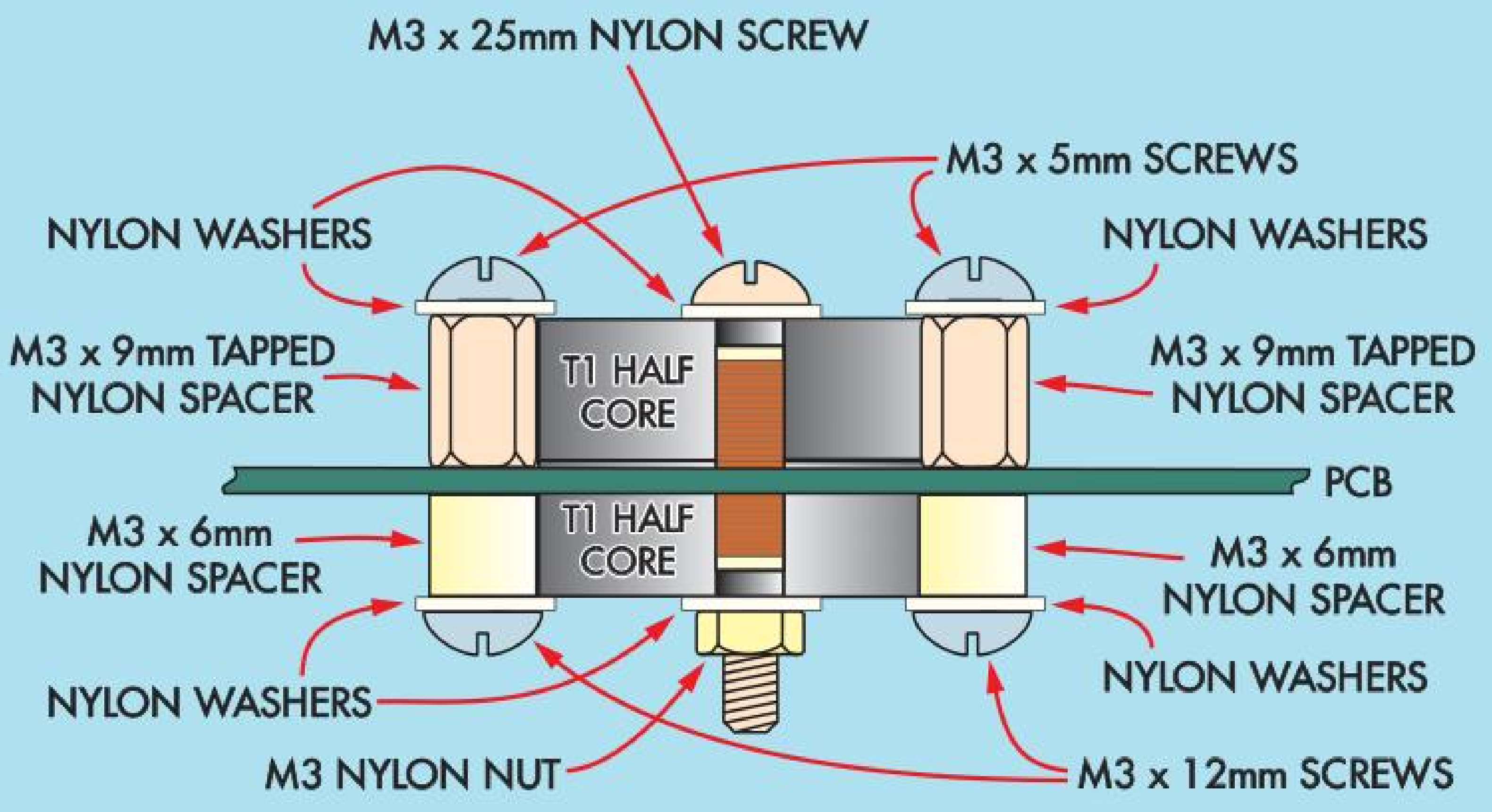

BOBBIN
PRIMARY WINDING 10 TURNS OF 0.5mm ENAMELLED COPPER WIRE
SECONDARY WINDING 3 LAYERS OF 40 TURNS EACH; 0.25mm ENAMELLED COPPER WIRE (120T TOTAL)

Fig.5: the transformer primary consists of 10 turns of 0.5mm-diameter enamelled copper wire (ECW), while the secondary is wound using 120 turns of 0.25mm-diameter ECW in three 40-turn layers. Note that one lead of each winding is brought out at the top of the bobbin, while the other is brought out at the bottom (see text and photos).





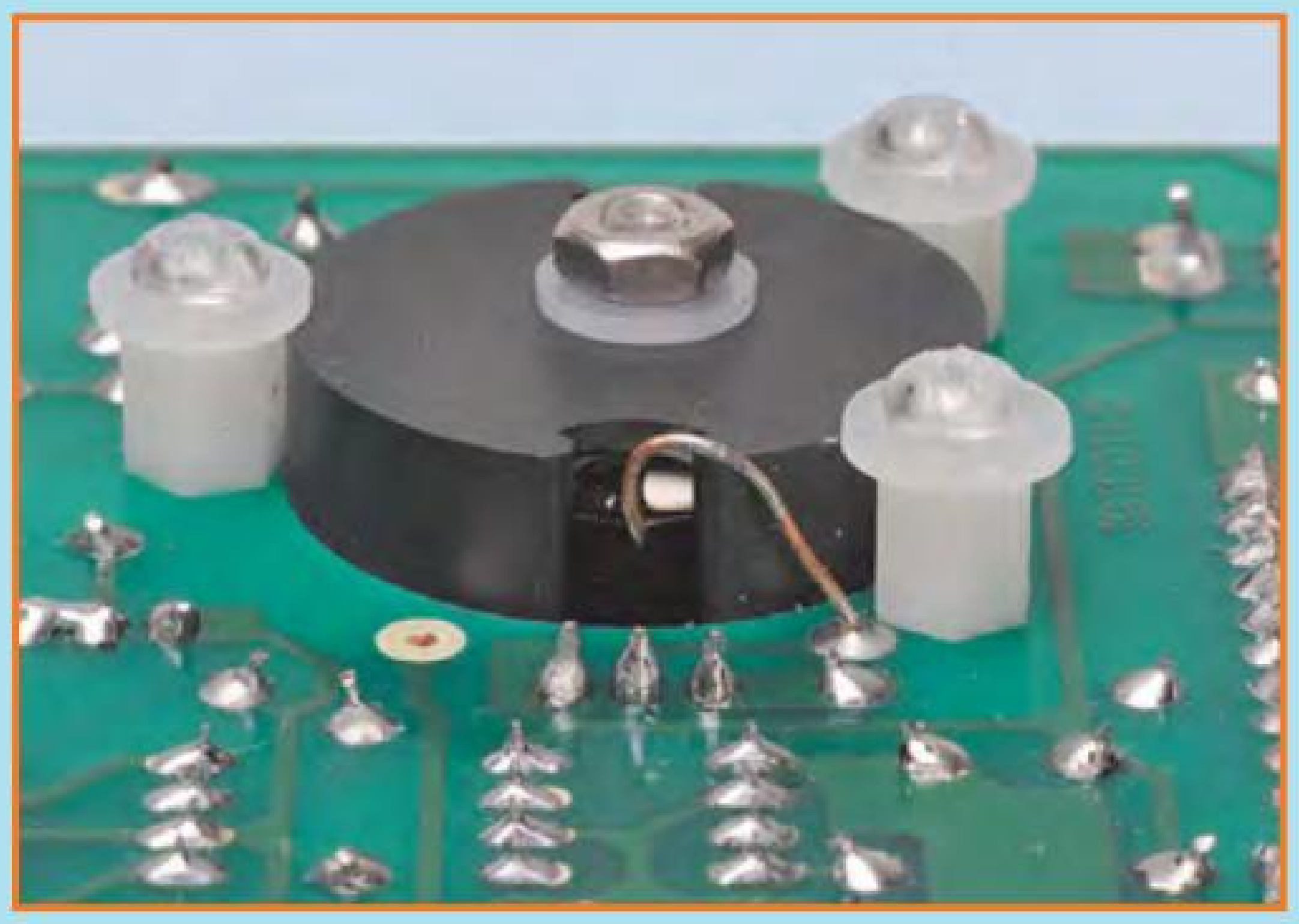


Fig.6: this diagram and the two photos at right show the mounting details for the transformer. It's secured in place using three sets of nylon spacers, nylon washers and nylon screws.

pins. That done, insert the socket strips into the holes on the PCB with the bargraph's anode at top right, as indicated by the chamfer on one edge (see Fig.4).

Finally, solder the pins so that the top of the display is 18mm above the PCB. It's best to solder one end pin first, then adjust the display as necessary before soldering the diagonally opposite end pin. The remaining pins can then be soldered once everything is correct.

Winding the transformer

Fig.5 shows the transformer winding details. It's wound on a plastic bobbin which is then fitted into a pot core assembly.

The primary goes on the plastic bobbin first and is wound using 10 turns of 0.5mm enamelled copper wire (ECW). These turns are wound on side-by-side (ie, close-wound), with the wire ends brought out through the notched exit points on the top and bottom of the bobbin. Once it's on, cover the winding with a layer of 10mm-wide insulating tape to hold it in place.

By contrast, the secondary consists of 120 turns of 0.25mm ECW and is wound using three 40-turn layers, each separated by a layer of insulation tape. As before, the start and finish windings exit from two notched exit points on the top and bottom of the bobbin.

The secondary is also close-wound, but note that 40 turns will not fit side-by-side across the bobbin. This means that some of the turns in each layer will have to go directly over the top of the others. Ideally, each layer should start on one side of the bobbin and be wound progressively toward the opposite side of the bobbin. Make sure that all three layers are wound in the same direction.

Secure the top secondary winding layer with another layer of insulation tape to hold it in place.

The next step is to cut an 11mm OD spacer from 0.25mm-thick cardboard. This spacer is used to separate the two pot core halves (it produces an air gap which prevents saturation in the ferrite cores). Once you've cut the spacer to size, cut a neat 3mm hole in its centre.

The pot core halves can now be placed over the bobbin with the spacer between them (ie, the spacer fits inside the bobbin). Check that the four leads from the bobbin exit through the core notches, then secure the core assembly using an M3 × 25mm screw, two nylon washers (one at the top and one at the bottom) and an M3 nut (see Fig.5). Cut off any excess screw length using side cutters.

The transformer is now fitted into its hole in the PCB with its 0.5mm primary leads to the left (ie, near Q2) and its 0.25mm secondary leads to the right (near D1-D4). One lead on each side will exit on the top of the PCB, while the other two leads exit the transformer on the underside of the PCB.

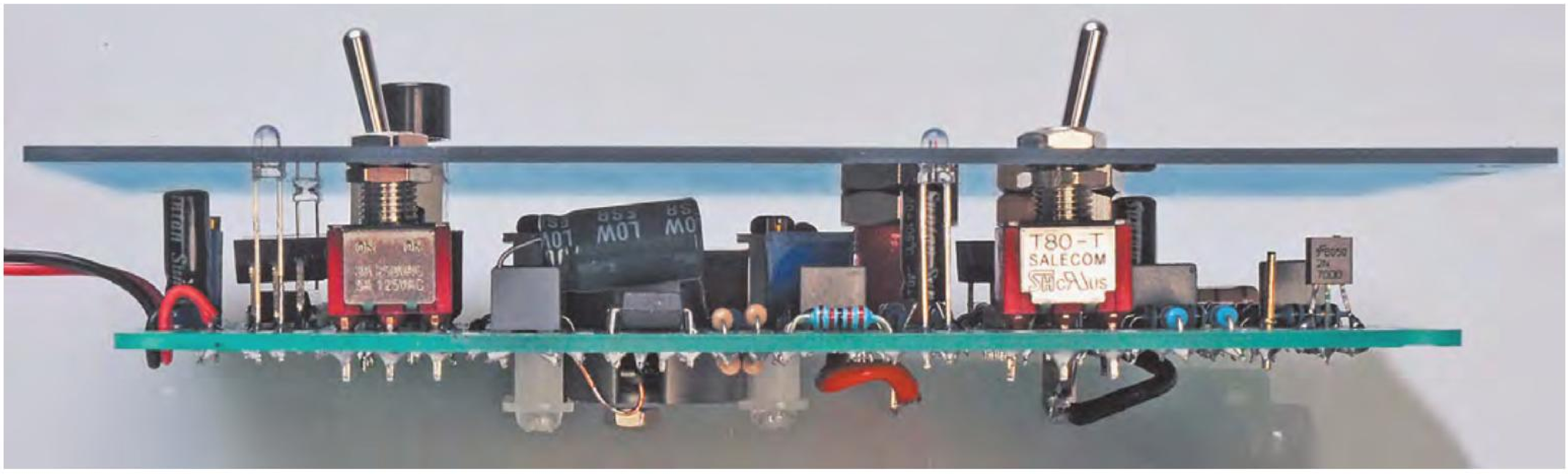
Once it's in position, secure the transformer in place using three M3 × 9mm tapped nylon spacers, three M3 × 6mm nylon spacers and M3 screws and washers – see Fig.6. The ends of the windings can then be trimmed, striped of insulation using a sharp knife and soldered to their respective pads on the PCB.

All that remains before the calibration procedure is to install the battery snap connector. Loop its leads through the two strain relief holes as shown on Fig.4 before soldering them to their pads.

Note that LEDs1-4 and the two banana socket terminals are not installed at this stage.

Test and calibration

Before going further, note that the inverter circuit generates a high voltage (up to 500V DC) and this can give you a nasty shock. In particular, note that the trip current protection circuit only works for connections between



The front panel PCB (with the insulated banana sockets fitted) is secured to the main PCB assembly by fitting it over the three switch shafts and doing up nuts on either side. Once it's in place, the LEDs are pushed through the front panel and soldered and the banana sockets connected to their respective test terminal pads.

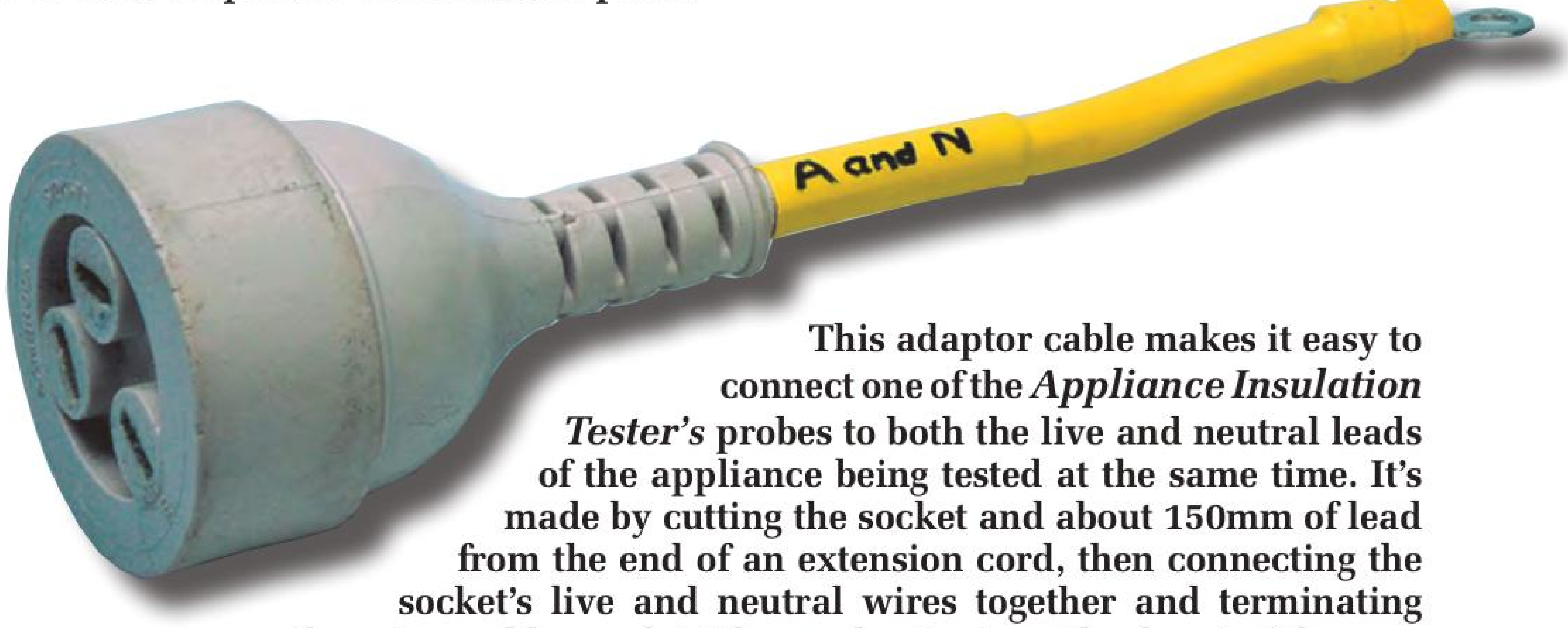
the '+' and '–' high-voltage terminals. It's there to provide protection against accidental contact with the output terminals, mainly when the unit is installed in its case.

Conversely, any contact between the circuit ground (or any other low-voltage point on the circuit) and high DC voltage on the '+' output will not cause the circuit to shut down. Take care and power up only when your hands are safely away from the PCB.

To test the unit, you will need to first solder short lengths (eg, 10mm) of red and black mains-rated wire to the '+' and '–' high-voltage PC stakes (the output sockets are not installed at this stage). The test and calibration procedure is as follows:

1) Connect a multimeter using clip leads across these '+' and '–' high-voltage leads and set S2 to the 500V position.
2) Apply power (keep your hands away from the leads) and check the high-voltage output. Assuming you get a reading, carefully adjust VR1 (using an insulated screwdriver) for a reading of 500V DC on the multimeter
3) Set S2 to its 250V position and check that the reading is 250V.
4) Switch off and connect a 1MΩ VR25 or VR37 resistor across the high-voltage terminal wires.
5) Set S2 for 500V, apply power and adjust VR2 anticlockwise until at least the third LED (from the left) in the LED bargraph lights.
6) Adjust VR2 clockwise until the second LED (the 1MΩ indicator) just lights, then set S2 to 250V and check that the unit shows the same 1MΩ reading on the LED bargraph.

That's it – the calibration procedure is complete.



This adaptor cable makes it easy to connect one of the *Appliance Insulation Tester's* probes to both the live and neutral leads of the appliance being tested at the same time. It's made by cutting the socket and about 150mm of lead from the end of an extension cord, then connecting the socket's live and neutral wires together and terminating them in a solder eyelet. The earth wire is cut back out of the way and the cable sleeved in heatshrink and marked. The appliance to be tested is plugged into this socket and one of the *Appliance Insulation Tester's* probes connected to the solder lug while the other probe goes to the appliance's external metalwork or chassis. (*UK readers will of course need to use a UK extension socket, not the one pictured above!*)

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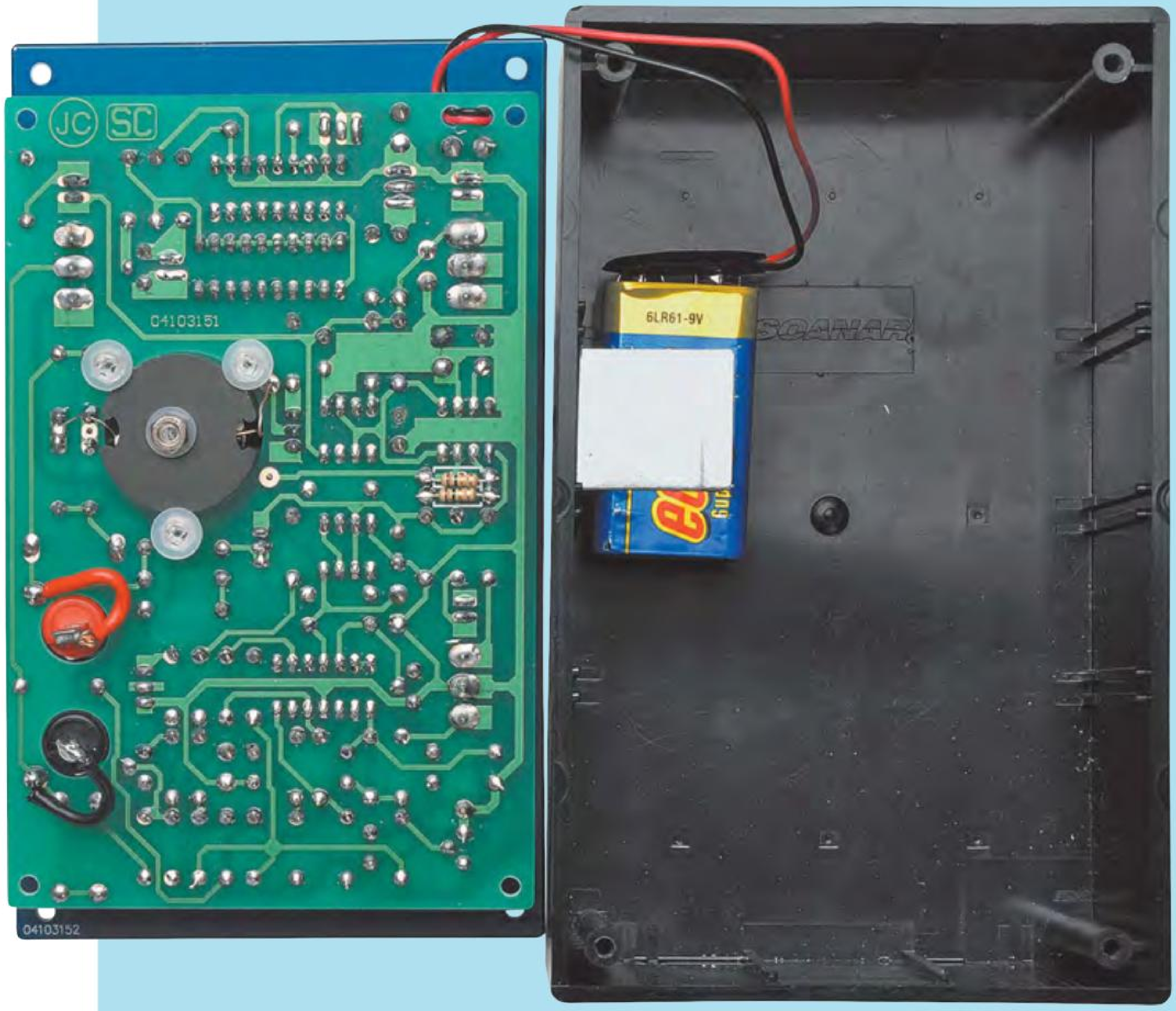

This is the view inside the completed *Appliance Insulation Tester*. The battery is clipped into a holder that's attached to the lefthand side of the case 15mm up from the bottom and between two sets of internal ribs.

APPLIANCE
INSULATION
TESTER

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An insulation resistance reading of around 4MΩ was the result when testing this old soldering iron. This indicates some leakage but it's still safe to use. By contrast, any appliance with an insulation resistance of 1MΩ or less is unsafe.

Final assembly

Now for the final assembly. First, insert LEDs1-4 into their PCB holes, noting that LED4 is green and that all LEDs mount with their anode lead towards the lower edge of the PCB. If the LEDs all have a clear body, you can usually determine which is the green LED by using the diode test feature on your multimeter. The LEDs may only glow dimly using this test, but that's all that's needed to reveal the colours.

Don't solder the LEDs at this stage – just leave them in place on the PCB.

Next, wind a single nut all the way down onto each switch mounting thread. Once these are in place, fit the red and black shrouded banana sockets to the front-panel PCB and secure them with the supplied nuts. Do the nuts up tightly, then fit the front panel over the three switches and push it down so that the LED bargraph goes into its rectangular hole.

Note that the corners of this rectangular hole may need to be 'squared off' using a file so that the bargraph will fit.

Now adjust the three previously-fitted switch nuts so the LED bargraph display sits flush with the top of the front panel. Check also that the panel is parallel to the PCB, then fit nuts to the top of the switch threads and tighten them down to hold the assembly together.

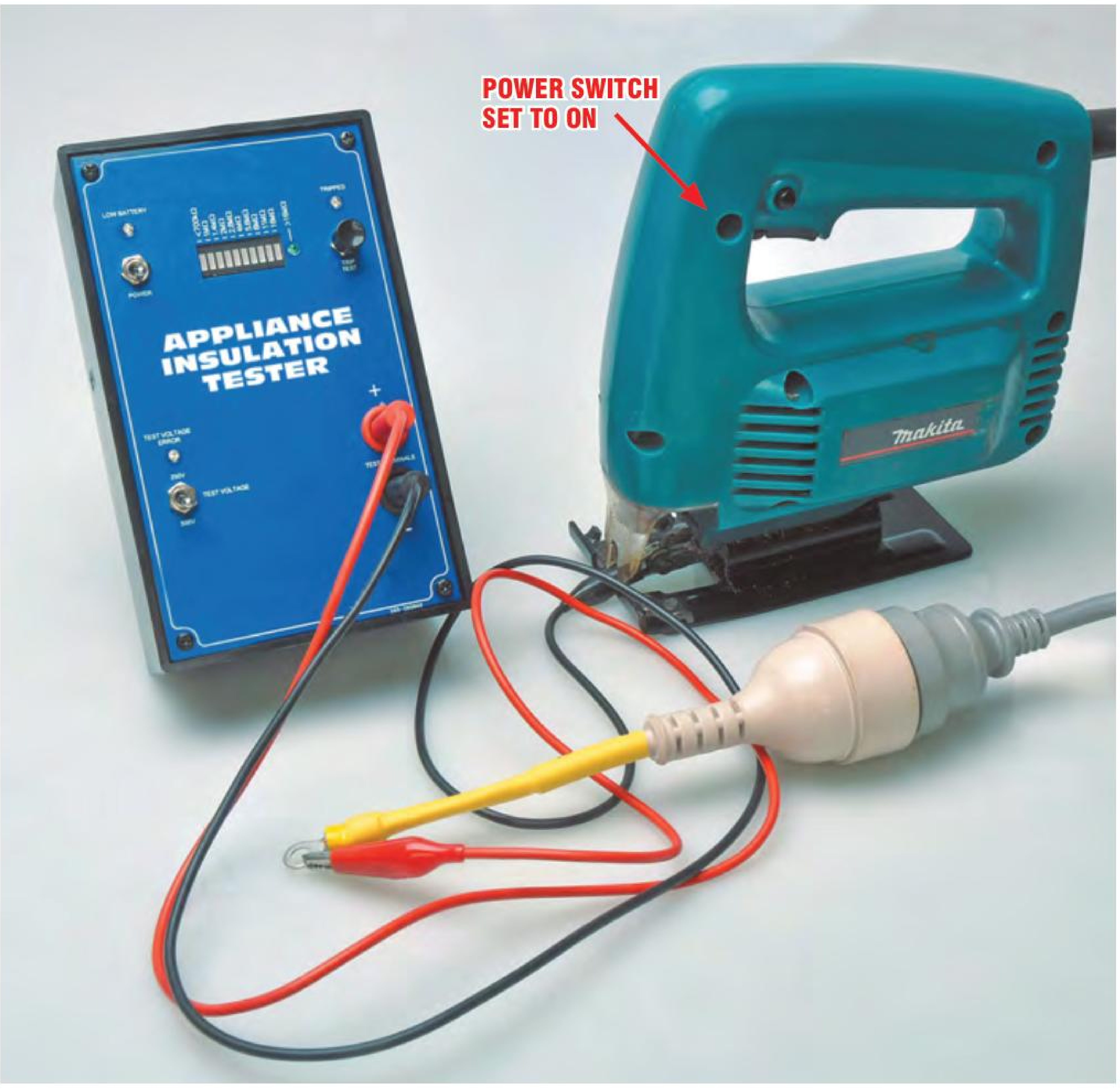
The four LEDs can now be pushed into their front panel holes and their leads soldered. In addition, you will need to solder the high-voltage output leads to the banana socket terminals.

Preparing the case

Only a small amount of work is required on the case. The first step is to attach a mounting clip for the 9V battery to the inner lefthand side. That's done by drilling a 3mm-diameter hole some 15mm up from the outside bottom of the box and between two sets of ribs (see photo). The mounting clip can then be attached using an M3 × 10mm screw and nut.

In addition, the internal ribs on the case ends must be cut down, as they prevent the front panel from sitting directly onto the four corner pillars. This can be done using side cutters or a sharp hobby knife.

The 9V battery can then be clipped into its holder and the completed PCB and front panel assembly lowered into position and secured using the supplied screws. That done, switch it



This jigsaw gave an insulation resistance measurement of >16MΩ on the 500V test range, indicating that it is safe to use.

on and check that the output voltages (250V and 500V DC) are correct.

Finally, press S3 to check that the Trip function works correctly. If it does, LED2 should light to indicate that this has occurred.

Testing appliances

When testing appliances, the condition of the mains plug, lead and earth connection (where used) will need to be checked. Make sure that mains wires are not frayed, repaired with insulation tape, broken or exposed. For earthed appliances, check the resistance between the earth pin on the mains plug and any exposed metal. There should be less than 1Ω resistance when measuring with a multimeter set to the low ohms range.

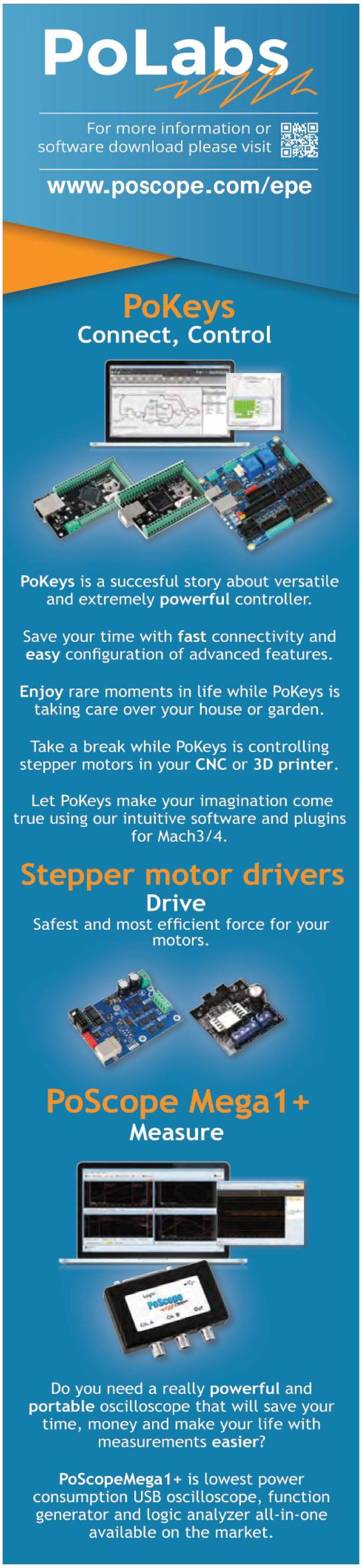
The accompanying photos show how the *Appliance Insulation Tester* is used to test a mains appliance. **One probe is used to simultaneously connect to both the live and neutral pins of the mains plug, while the other probe connects to any exposed metal parts on the appliance. The appliance's power switch must be on.**

Note that some metal parts may be painted or anodised and so contact with bare metal will not be made with the probe. The way around this is to scrape away any coating (without causing too much unsightly damage) so that a proper connection is made to the metal.

The live and neutral mains plug connection can be made using a large clip attached to the probe. Alternatively, the appliance could be plugged into an extension cord mains socket which has its live and neutral leads brought out, connected together and terminated in a crimp eyelet for easy connection to the tester – see photos.

Note that normally a 500V insulation resistance test should be made, but when an appliance test fails because of internal over-voltage protection (eg, if MOVs are fitted), then a 250V test can be made instead.

Any appliance that has a measured insulation resistance of 1MΩ or less is unsafe. Note, as mentioned in the introduction, that this does not apply to portable RCDs that have a functional earth or for mineral insulated metal sheath heating elements.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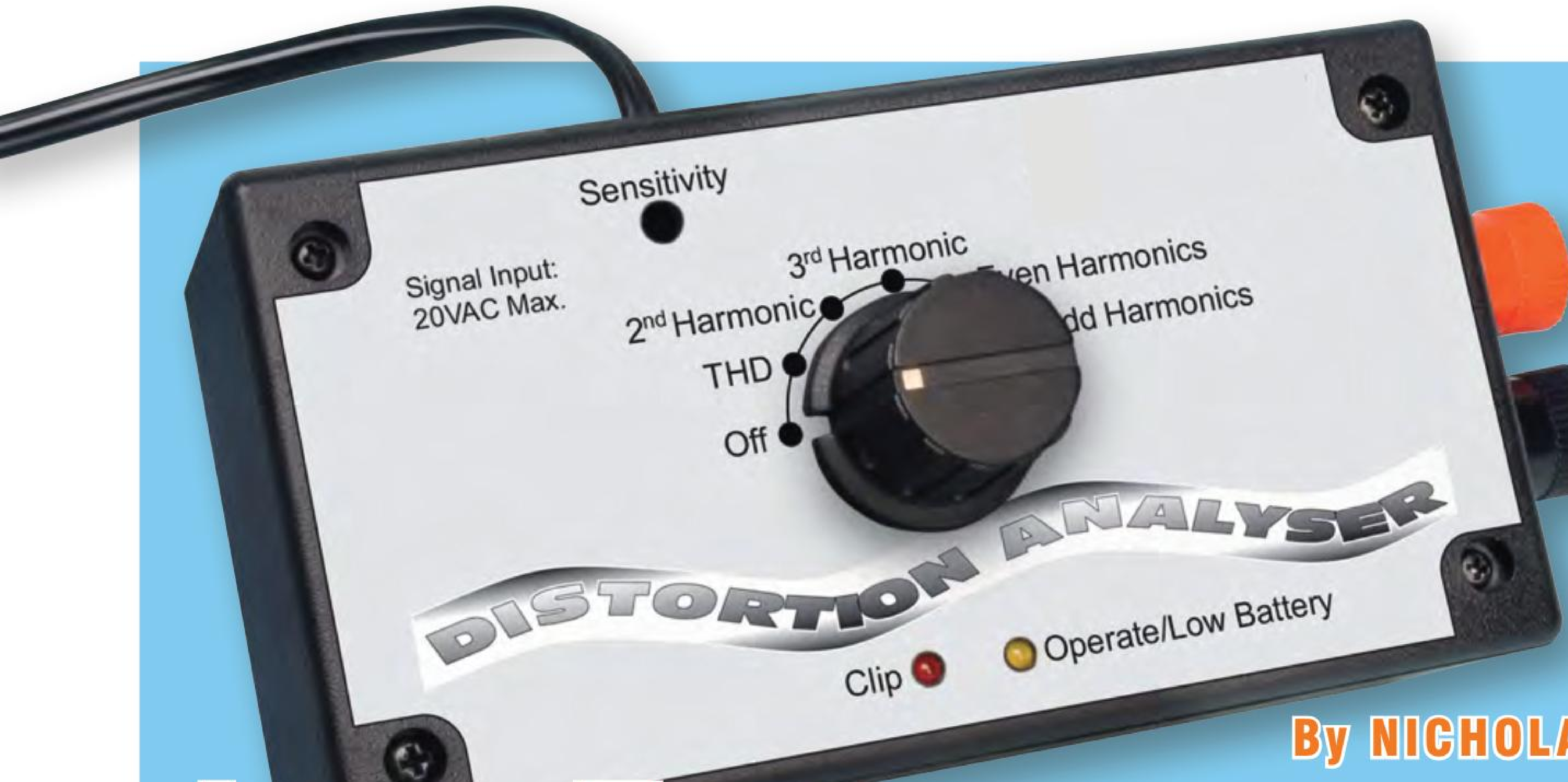

By NICHOLAS VINEN

Low Frequency Distortion Analyser

Are you concerned about the quality of your 50Hz 230VAC supply? Would you like to measure the harmonic distortion of your loudspeaker system? This unit will measure the distortion of a 50Hz or 60Hz mains waveform (via a low-voltage isolating transformer) or the distortion of any 3-20VAC sinewave signal in the range of 20Hz-10kHz, eg, the output of a midrange or bass loudspeaker.

WE TEND TO think of the 50Hz AC mains supply as a 230V RMS sinewave, but if you have a look at it on an oscilloscope (see Fig.1), it is often quite distorted. A large proportion of mains loads are not resistive but reactive, and since they draw current out-of-phase or in a non-sinusoidal manner, they generate a voltage across the finite impedance of the mains supply network and distort the signal.

Typical 'waveform distorters' are fluorescent and gas discharge lights and devices with transformer/rectifier-based linear power supplies or non-PFC (power factor correction) switch-mode power supplies. These tend to draw current only at the voltage peaks, leading to the 'flat-topping' you can see in Fig.1.

Does this matter? Well, most equipment will not be affected by even quite severe levels of mains distortion but some sensitive devices could be upset. As an extreme example, there are plenty of devices which will not operate correctly from square-wave inverters and some devices won't operate from modified sinewave inverters either.

Having said that, the distortion levels of such inverters are well above the maximum allowable figure for the mains supply, which is normally quoted as 5%. In our experience, a typical harmonic distortion figure is around 3%, but it varies quite a bit depending on location. Interestingly, different power points in our office gave quite different readings, from 2.4-3.2%, suggesting that they are wired to different mains phases.

And yes, this analyser can be used to (indirectly) check the distortion of portable 230VAC generators and inverters. **It's safe to use because a small 3-20VAC plugpack is used as an isolation transformer** (ie, the plugpack is plugged into the generator or the mains and the plugpack's low-voltage AC output is fed into the signal input of the analyser).

So how would you know whether your mains supply is badly distorted? Well, this simple device will tell you. It can measure harmonic distortion from below 0.1% to around 33% with a bandwidth of a few kilohertz and it's very simple to build and operate.

Some devices which may be sensitive to mains distortion include certain types of (mainly older) test equipment and medical devices. Devices with motors will still run with highly distorted mains but some may get hotter than normal. Severe harmonics, such as those present when mains tone control signals are being broadcast, can also cause transformers, motors and fluorescent light ballasts to hum or buzz audibly.

Some Hi-Fi enthusiasts also believe that AC mains waveform distortion and noise can affect the sound quality of amplifiers and other equipment. In our experience, while control tones and some mains-borne interference may become audible, that tends to be more likely in valve amplifiers. Otherwise, typical distortion of the 50Hz (or 60Hz) mains waveform is not likely to have any effect on audio performance.

However, there is one exception. If the mains waveform is severely 'flat topped' that means that its peak-to-peak value will be significantly reduced with respect to an undistorted sinewave. That in turn means that the resulting supply voltages in the amplifier can be less than they should be and that can definitely affect performance, particularly if the amplifier is being driven hard.

For more information see this link: **www.mantenimientomundial.com/sites/mm/notas/Harmonics.pdf**

If you want to measure loudspeaker distortion you will need a microphone and preamplifier.

How it works

Traditional audio analysers use a tunable notch filter. The filter removes the fundamental frequency (eg, 50Hz or 60Hz for a mains supply) and the remaining harmonics and noise are measured and related to the input voltage to obtain a percentage reading.

This project idea was initially suggested to us as a series of passive notch filters driven by a low-voltage transformer. The notches would be tuned to the local mains frequency (ie, 50Hz), thus removing the fundamental. The residual signal (ie, distortion components) could then be measured with a DMM and divided by the raw transformer output voltage in order to calculate the THD+N figure as a percentage. We investigated this concept but concluded that passive filters are too fiddly to tune and too lossy for this purpose. Tuning is a tricky issue because such filters inevitably involve capacitors which are not normally sold in tolerances better than 5%. So each notch stage would need at least one trimpot and they would all need

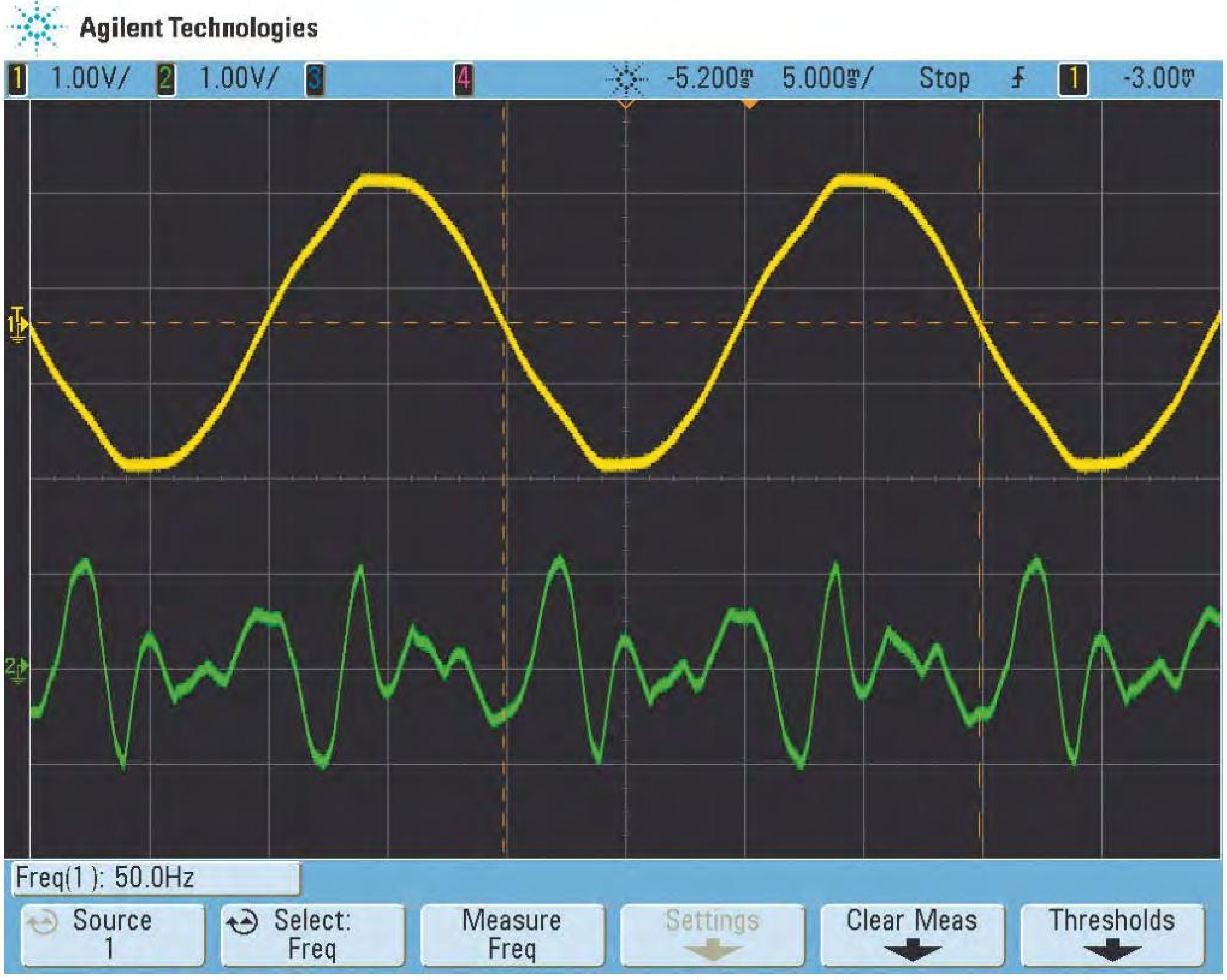

Fig.1: a typical mains waveform, as measured at our office (yellow, top) with its distortion residual (green, bottom). Not only are the peaks badly flattened, but also there are visible bumps along the rising and falling edges, especially around the zero-crossing points. It isn't obvious from the residual, but the distortion is almost all odd-order harmonics (3rd, 5th,...) due to the flat-topping. This is very similar to the distortion in an audio amplifier when the output is clipping.

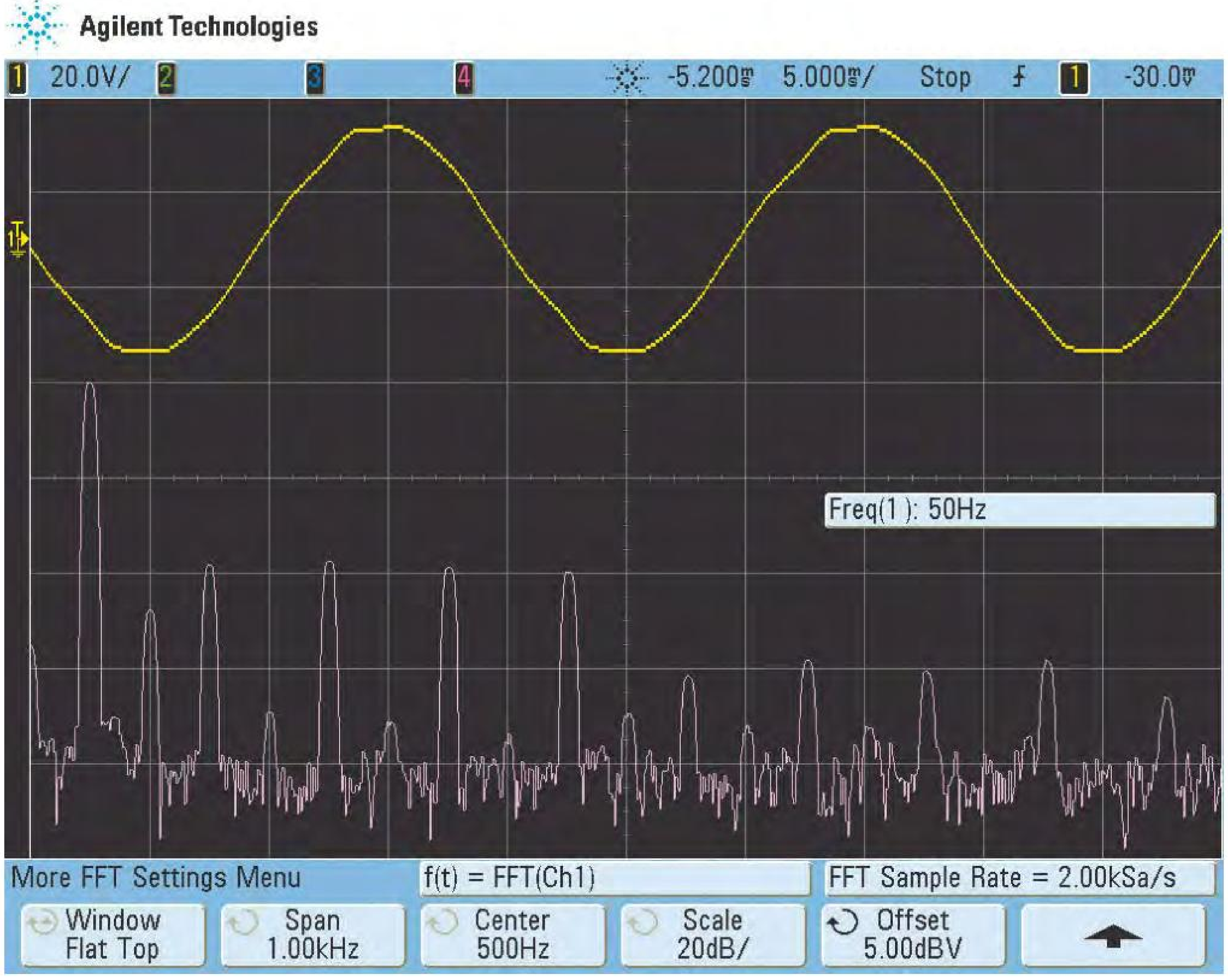

Fig.2: at top is the same distorted mains waveform as in Fig.1 with a low-pass filter applied to remove noise; below is the spectrum calculated by the scope from this data using a Fast Fourier Transform. It is configured to use the same Flat Top window as the microcontroller in this project. You can see that the third, fifth, seventh and ninth harmonics are dominant at around -39dB, with a second harmonic at about -48dB. The number of harmonics shown is about the same as the micro uses to calculate total distortion.

Parts List

1 double-sided PCB, available from the *EPE PCB Service*, coded 04104151, 104 × 60.5mm
1 UB3 jiffy box (optional)
1 5kΩ mini horizontal trimpot (VR1)
1 28-pin DIL IC socket (for IC1)
1 9V battery snap
1 9V battery
1 piece non-conductive foam, approximately 65 × 40 × 8mm
1 PCB-mount DC socket (optional) (CON1)
1 2-way terminal block, 5.08mm spacing (CON2)
1 5-pin right-angle header (CON3) (for programming IC1)
1 2-pole 6-position rotary switch (S1)
1 knob to suit S1
2 PCB stakes
2 chassis-mount binding posts (optional, for use with case)

Semiconductors
1 PIC32MX170F256B-I/SP programmed with 0410415A.HEX (IC1)
1 78L05 100mA regulator (REG1)
2 MCP1700-3.3/TO 3.3V low-dropout regulator (REG2)
1 yellow or orange 3mm LED (LED1)
1 red 3mm LED (LED2)
1 1N4004 1A diode (D1)
1 1N5819 1A Schottky diode (D2)

Capacitors
1 220µF 25V electrolytic
3 100µF 16V electrolytic
1 10µF+ 6V tantalum or SMD ceramic
1 1µF multi-layer ceramic
3 100nF multi-layer ceramic

Resistors (0.25W, 1%)
3 100kΩ
1 33kΩ
3 10kΩ
1 1kΩ
2 470Ω
1 22Ω
1 10Ω

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to be tuned very close to 50Hz to get a deep enough notch for sufficient fundamental rejection.

However, the real show-stopper for the passive filter idea is its inherent signal loss and its lack of notch depth; you need a really steep notch to remove the fundamental but have no effect on the harmonics. A simulation of the required filter with ideal components showed that the first few harmonics (ie, 100Hz, 150Hz, 200Hz etc) were severely attenuated by the shoulders of the notch, making the resulting reading likely to severely underestimate the actual level of distortion.

The third harmonic at 150Hz is normally the largest component of mains distortion and a twin-T passive notch filter tuned for 50Hz is still 10dB down at this frequency. If multiple such filters were used (and it seems likely this would be required), the attenuation would be 20dB or more and this is clearly unacceptable.

We did consider using active notch filter(s) but to get the required notch depth with sufficiently little attenuation for the second harmonic at 100Hz would require a complex circuit. The alternative is to use digital signal processing with a microcontroller.

DSP software to the rescue

The DSP concept is relatively simple, even if the software is not. The output of a 9VAC or 12VAC plugpack is attenuated to give a signal of about 3.3V peak-to-peak. This is fed to the analogue-to-digital converter (ADC) input of a 32-bit microcontroller. The micro digitises the signal, does some filtering to make up for its relatively low-performance internal ADC, then does a spectral analysis and determines the THD from the result.

The output from the microcontroller is a pulse-width modulated (PWM) signal which is filtered to obtain a DC voltage that can be read with a multimeter or panel meter. So the circuit is really quite simple even though the software is anything but.

In fact, we use a Fast Fourier Transform (FFT) to produce a spectrum analysis of the input signal. This tells us the amplitudes of the fundamental frequency and all the harmonics up to the 20th. The tallest peak will be the 50Hz fundamental and the micro can easily search for the highest peak, so frequency accuracy is not important. The distortion components (ie, the harmonics) will be at equally spaced frequencies above this peak. These calculations are performed in the frequency domain.

As hinted at earlier, the formula for computing THD (in the time domain) is to divide the RMS average of the residual signal (ie, signal minus 50Hz fundamental sinewave) by the RMS average of the fundamental sinewave itself, then take the square root of the result. It isn't hard to do this in the frequency domain, as the spectral peaks correspond to the RMS voltages of each individual sinewave component.

In theory, the answer is the same although the time-domain method inevitably includes any noise within the measurement bandwidth of the instrument while the spectral version gives the possibility of ignoring noise and only considering the harmonics themselves, thus giving a THD (only) measurement rather than THD+N.

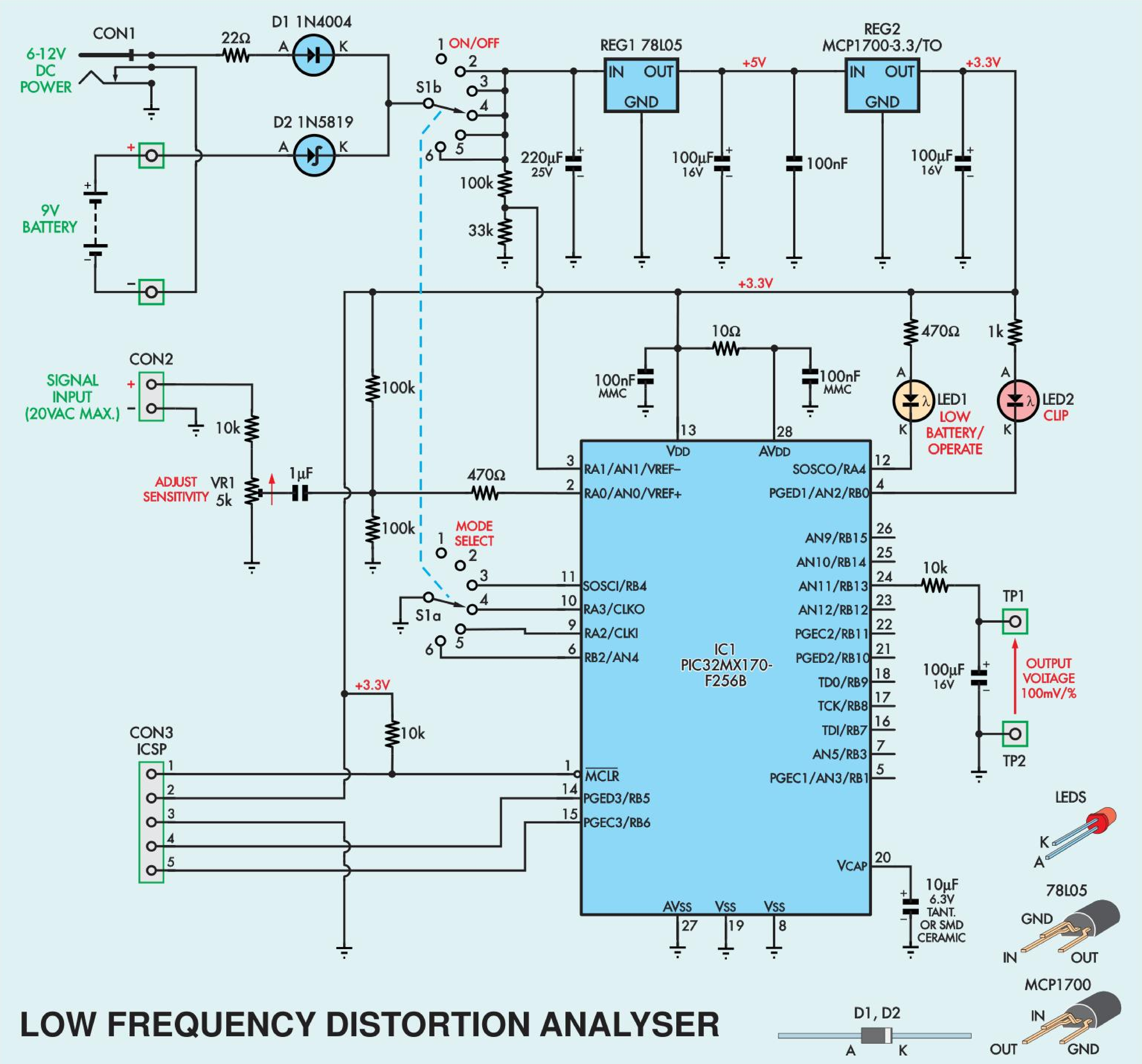
In this case, it's necessary because the micro's 10-bit ADC has a lot of aliasing noise and this would cause a THD+N reading to be much too high. Also, if mains noise is going to cause any problems, it's most likely to be due to RF emissions. This would not normally contribute much to a THD+N reading, partly because the absolute power is low and partly due to the typically limited bandwidth of the measurement.

Other uses

The aforementioned distortion measurement method is sufficiently generic that it could be used for other purposes. Because the unit searches for the fundamental, the THD of any signal in the range of 20Hz-10kHz can be measured. However, given that the output starts to become less accurate at lower readings (<0.1%) and the lowest reading you're likely to get is around 0.03%, it isn't suitable for measuring Hi-Fi audio amplifiers.

Having said that, it certainly should be suitable for measuring the kind of distortion that's typical for... ahem a valve amplifier. The lowest readings the device can give are more or less in line with the best performance expected from a valve amplifier. And with solid-state amplifiers, it's good enough to at least check that an amplifier is operating correctly and so it might be useful for servicing work.

In order to provide relatively accurate readings at higher frequencies,


CON1
6-12V DC POWER
22Ω
D1 1N4004
A
K
D2 1N5819
+
9V BATTERY
−
1 ON/OFF
2
3
4
5
6
S1b
100k
33k
220µF 25V
REG1 78L05
IN
OUT
GND
+5V
100µF 16V
100nF
REG2 MCP1700-3.3/TO
+3.3V
100µF 16V
+3.3V
10Ω
100nF MMC
100nF MMC
470Ω
1k
LED1 LOW BATTERY/ OPERATE
LED2 CLIP
CON2
SIGNAL INPUT (20VAC MAX.)
10k
ADJUST SENSITIVITY
VR1 5k
1µF
470Ω
100k
100k
MODE SELECT
S1a
+3.3V
10k
CON3 ICSP
13
28
VDD
AVDD
3 RA1/AN1/VREF−
2 RA0/AN0/VREF+
11 SOSCI/RB4
10 RA3/CLKO
9 RA2/CLKI
6 RB2/AN4
1 MCLR
14 PGED3/RB5
15 PGEC3/RB6
IC1 PIC32MX170-F256B
SOSCO/RA4 12
PGED1/AN2/RB0 4
AN9/RB15 26
AN10/RB14 25
AN11/RB13 24
AN12/RB12 23
PGEC2/RB11 22
PGED2/RB10 21
TDO/RB9 18
TCK/RB8 17
TDI/RB7 16
AN5/RB3 7
PGEC1/AN3/RB1 5
VCAP 20
AVSS 27
VSS 19
VSS 8
10k
TP1
100µF 16V
OUTPUT VOLTAGE 100mV/%
TP2
10µF 6.3V TANT. OR SMD CERAMIC
LEDS
K
A
78L05
GND
IN
OUT
MCP1700
IN
OUT
GND
D1, D2
A
K

LOW FREQUENCY DISTORTION ANALYSER

Fig.2: the *Distortion Analyser* circuit. There isn't much to it since most of the work is done in IC1's software. The signal is attenuated by VR1 and then biased to half-supply (1.65V) before being applied to analogue input RA0. A PWM signal from pin 24 (RB13) passes through a low-pass RC filter with the reading available between TP1 and TP2. Power comes from a 9V battery or DC plugpack, while rotary switch S1 provides both on/off switching and mode selection.

the unit automatically increases its sampling rate (by reducing the amount of averaging done) when it detects that the fundamental is at a higher frequency.

Circuit description

The full circuit is shown in Fig.2. It would normally be powered from a 9V battery via Schottky reverse polarity protection diode D2, but it could be powered from a DC plugpack via diode D1. **It cannot be powered from the same 9-12VAC plugpack which is used to couple the 50Hz mains AC signal into the analyser.**

If a plugpack is used to power the *Low Frequency Analyser*, the 9V battery is disconnected by the socket switch, CON1. D1 provides separate reverse-polarity protection for the plugpack. The DC supply is connected to the circuit via one pole of 6-position 2-pole rotary switch S1.

Two 3-terminal regulators are connected in series to provide a 3.3V supply for the microcontroller. The first is REG1, a 78L05 5V regulator which acts as a pre-regulator for 3.3V regulator REG2, which can only handle a maximum input voltage of 6V.

In practice, this two-regulator combination provides a regulated 3.3V rail (important for accuracy of the output voltage) for input voltages down to about 5V, which would mean the 9V battery was well and truly flat.

So that you know if the battery has gone flat, a 100kΩ/33kΩ resistive divider allows PIC32MX17F256B microcontroller IC1 to monitor the battery voltage at its AN1 analogue

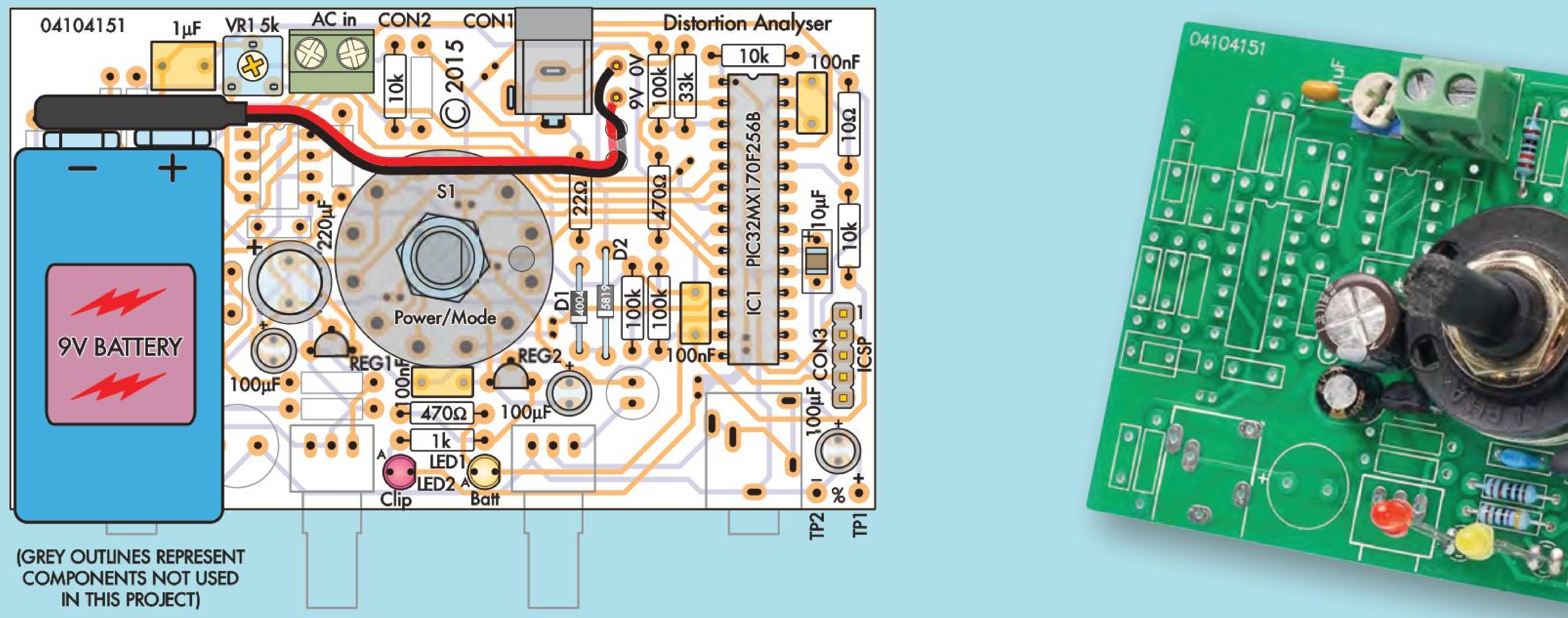


Fig.3: follow this PCB overlay diagram and the photo at right to build the *Distortion Analyser*. Note that many of the components are left off as this PCB was designed to be used for multiple purposes. It snaps into the side rails on a UB3 jiffy box or can be housed in a larger enclosure if a panel meter is to be fitted, to display THD readings.

input (pin 3). The 3.3V rail is used as a reference and if the voltage of the battery drops below about 5.6V, LED1 is illuminated.

The input signal is fed in via CON2 and has a 15kΩ fixed resistive load. **This minimal loading means that a 9VAC or 12VAC transformer's output closely tracks the mains waveform, ie, the transformer itself causes minimal extra distortion.** The signal is then coupled via a 1µF capacitor and DC-biased to 1.65V (half the 3.3V supply) by a pair of 100kΩ resistors. The signal then goes to analogue input AN0 (pin 2) of IC1 via a 470Ω protection resistor.

The chip uses its internal RC (resistor/capacitor) oscillator and PLL (phase-locked loop) to run at 24MHz, so that its FFT calculations on the sampled data at AN0 complete fairly quickly. The ADC requires 13 clocks per sample (1 for sampling, 12 for conversion) and is run at a quarter the main clock rate, giving a sampling rate of 24MHz ÷ 13 ÷ 4 = 460kHz.

Between 1 and 16 samples are averaged, giving an effective sampling rate of between 28.75kHz and 460kHz. For a 50Hz signal (eg, mains) at 28.75kHz and a window size of 8192 samples, this means 8192 / 28750 = 285ms worth of data or just over 14 full cycles is processed at a time.

Having done the THD calculation, the micro then uses one of its internal PWM peripherals to generate a signal at output RB13 (pin 24). The associated timer period is set to 3300 so that for each increment in the PWM duty cycle value, the average output voltage increases by 1mV. This assumes an accurate 3.3V rail; the MCP1700 has an output voltage tolerance of ±0.4% at 25°C, so it should be well within ±1% at normal room temperatures.

This PWM signal passes through a 10kΩ/100µF RC low-pass filter with a time constant of around one second. This gives a DC voltage to make the meter's job easier and also to smooth out any jitter in the measurement due to noise and so on. It can then be measured between TP1 and TP2.

Each time the output voltage is updated, LED1 is flashed briefly. This indicates that the unit is operating. As mentioned earlier, IC1 monitors the battery level via its AN1 input and should the battery voltage drop to a low level (before output accuracy suffers), the state of LED1 is inverted. That is, LED1 is switched on all the time, except briefly when the output voltage is updated when it flickers off.

Thus, if LED1 is on most of the time, the battery is flat and should be changed.

LED2 is used to indicate ADC overload on input AN0. For optimum performance, VR1 is adjusted to just below the level where LED2 lights. Having said that, the exact setting is not critical as long as LED2 remains off during operation; if VR1 is set a little low, it doesn't appear to affect the readings much.

Rotary switch S1a connects either pin 6 or one of pins 9-11 of IC1 to ground. With S1 in position 1, power is disconnected so the unit is off. IC1 can determine which of the other five

Features and Specifications

Input signal voltage: 3-20V RMS

Input signal frequency: 20Hz-10kHz

THD measurement range: 0.03-33%

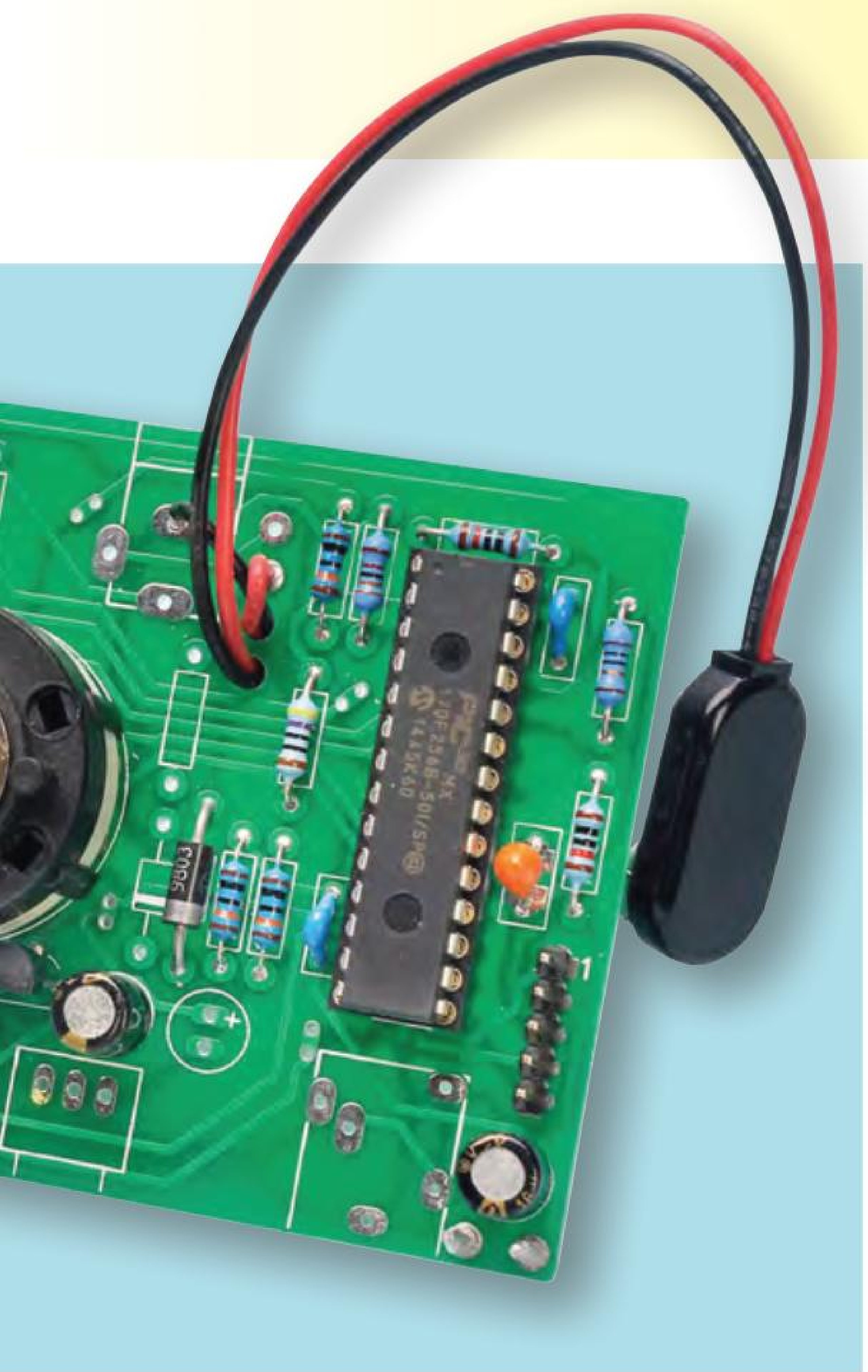
THD measurement accuracy: typical error less than 0.1% (absolute)

Modes: total distortion %, second harmonic %, third harmonic %, even harmonic % and odd harmonic %

Power supply: 9V battery or 6-15V DC plugpack

Operating current drain: ~15mA

Low battery indicator: LED, ~5.5V threshold



positions the switch is in by enabling its weak internal pull-up current sources on these pins. If S1 is in position 2, none of these pins (6 or 9-11) is pulled low, whereas positions 3-6 each pull a different pin low.

IC1 checks the state of S1 immediately after it updates its output and performs a slightly different measurement at the next update, depending on its state. In position 2, the normal THD calculation is made. In position 3, only the THD contribution from the second harmonic is read out. Similarly, position 4 reads the third harmonic only, position 5 gives the THD contribution of all even harmonics (2nd, 4th, 6th,...) and position 6 reads only odd harmonics.

CON3, the ICSP header, is used to program IC1 and is not required if you are using a pre-programmed chip. The remaining components in the circuit are the two supply bypass capacitors for IC1's V_{DD} and AV_{DD} rails, a 10Ω resistor to help filter its analogue supply and a 10µF capacitor at pin 20 (V_{CAP}), which is used by its internal core regulator. This 10µF capacitor must be a low-ESR type (below 1Ω) which means either tantalum or ceramic.

Construction

Building this unit is straightforward, with most of the parts mounted on a PCB, available from the *EPE PCB Service*, coded 04104151. Note that there are a number of blank component locations, as this PCB was designed for other uses as well.

Fig.3 shows the parts layout on the PCB. Start by checking the resistor values with a DMM and fit them where shown. Follow with diodes D1 and D2; these are different types and are both oriented with their cathode stripes facing the bottom edge of the PCB.

Next, fit the IC socket with its notched end towards the top of the board. Check that it's sitting flat after soldering two diagonally opposite pins, then make the rest of the joints. Follow with the ceramic capacitors, trimpot VR1 and then the two regulators. Don't get the latter mixed up and note that you will probably need to crank their leads out with small pliers before mounting them so that they fit the pads.

If fitting the DC socket, do so now. Similarly, you can install pin header CON3 but note that it isn't required if you have a pre-programmed chip.

Now fit the two PCB stakes at lower right, followed by the tantalum and electrolytic capacitors. These capacitors are all polarised, with the longer (positive) leads all going towards the top of the board. If fitting CON3, lay the adjacent 100µF electrolytic capacitor over, otherwise you will have trouble plugging the PICkit programmer in.

CON2 can now go in, making sure its wire entry holes go towards the nearest edge of the board. That done, trim about 10mm from the end of switch S1's shaft, leaving it 30mm long, as measured from the top of the switch body. File off any burrs and check that the knob still fits, then mount S1 on the PCB.

Be careful with S1's orientation as there are two possible ways it can go in. The plastic locating spigot must go towards IC1, as shown in Fig.3

Once the switch is in, feed the battery snap leads through the two strain relief holes and solder them in place. Note that if you haven't fitted CON1, you will also need to solder a wire link between its pad nearest the edge of the board and the vertical pad immediately to its left and slightly below. This replaces CON1's internal switch. Without this, the circuit won't get any power from the battery.

The two LEDs are fitted at almost full lead length, with the base of their lenses 25mm above the top of the PCB (use a cardboard spacer). This allows them to just poke through the lid of the jiffy box. If you aren't using a jiffy box, you could just push them all the way down onto the board. Either way, both anodes (the longer leads) go towards the left.

We used a red LED for the clipping indicator (LED2, at left) and yellow for the operation/low battery indicator (LED1, at right) but you can change the colours if you want. You may need to adjust the current-limiting resistors to suit though.

You can now plug microcontroller IC1 into its socket, ensuring it has the correct orientation, ie, pin 1 towards upper left. If your chip is blank, use an in-circuit programmer to flash it now, via CON3. You can power the chip from the programmer if it has that capability (the PICkit3 does) – if not, apply DC power to CON1 or the battery snap.

Table 2: Capacitor Codes

Value	µF Value	IEC Code	EIA Code
1µF	1µF	1u0	105
100nF	0.1µF	100n	104

Table 1: Resistor Colour Codes

☐	No.	Value	4-Band Code (1%)	5-Band Code (1%)
☐	3	100kΩ	brown black yellow brown	brown black black orange brown
☐	1	33kΩ	orange orange orange brown	orange orange black red brown
☐	3	10kΩ	brown black orange brown	brown black black red brown
☐	1	1kΩ	brown black red brown	brown black black brown brown
☐	2	470Ω	yellow violet brown brown	yellow violet black black brown
☐	1	22Ω	red red black brown	red red black gold brown
☐	1	10Ω	brown black black brown	brown black black gold brown

Calculating distortion using a Fourier transform

Total harmonic distortion is defined as the ratio of the RMS voltage of a signal's harmonics to the RMS voltage of the signal itself (the signal normally being a sinewave). The traditional method for measuring the THD of a sinewave is to align a deep, adjustable notch filter with the fundamental frequency, measure the RMS voltage of the residual, then divide this by the RMS voltage of the signal.

However, this calculation can also be done based on a spectral analysis of the signal. Spectral analysis breaks the signal down into a series of sinewaves with various frequencies, amplitudes and phases. When these sinewave components are summed, the original signal is reconstructed.

We can find the fundamental by looking for the sinewave component with the largest amplitude and we can then find its harmonics at integer multiples of the fundamental frequency. The ratio of the sum of harmonic amplitudes to the fundamental amplitude then gives us the THD figure.

Note that this is not THD+N since we're only looking at the harmonic amplitudes and not the wideband noise (which would also be at frequencies below the fundamental and between the fundamental and harmonics).

That all sounds relatively easy, but there are quite a few tricks to it. First, we need to discuss the use of the Fast Fourier Transform method, which is used to convert the sampled time-domain data to frequency-domain (ie, spectral data).

The input to a Fourier transform is typically a buffer with a power-of-two number of sample values, encoded as complex numbers. Normally, the complex numbers would initially have a zero imaginary portion, ie, they are real numbers nominally in the range of –1 to 1 (we're using some tricks here to get extra performance, but we'll explain them later; for now, assume that's true).

The Fourier transform converts these complex numbers into another set of numbers of identical size, the magnitude of which indicate the amplitude of the component sinewaves at a set of evenly spaced frequencies. For example, say we have a 4096-entry buffer (2^{12}) and the sampling rate is 8192Hz.

The magnitude of the resulting complex number at index #1 indicates the amplitude of the sinewave component at 1Hz, index #2 at 2Hz and so on, up to 2047Hz (ie, half the Nyquist limit). The complex 'angle' of these values indicates the relative phase of the constituent sinewaves but we aren't really interested in that.

So you might expect that if you performed an FFT transformation on a pure sinewave at say 100Hz, you would be able to read out its amplitude at index #100 and all the other values would be zero, indicating the lack of any other frequencies in the signal. However, with the naive implementation of the FFT, as well as getting a positive magnitude at index #100, you also get lesser values at index #101, index #102, etc with decreasing values. The result is similar at lower indexes, ie, #99, #98, etc.

In fact, you will get a non-zero value in every single 'bin'. That's because of the fact that in the 4096-sample window, the signal abruptly starts at sample #0 and ends at sample #4095. These sudden start and end transitions cause this 'blurring' of the data.

Windowing

This problem is mitigated to a large extent by the practice known as 'windowing' the data. This is akin to a piece of music which fades in at the start and fades out at the end – you lose the abrupt transitions at these points. There are infinitely different ways to do this (which vary by the rates of 'fade-in' and 'fade-out') and depending on which windowing method you use, the result has different properties.

Basically, different methods provide different compromises as to how much the 'blurring' is reduced versus how much the magnitudes are altered. Popular windowing methods include Hann (also known as Hanning), Hamming, Blackman-Harris and Flat Top. If no such function is applied, this is known as a 'Rectangular Window'. There is an excellent Wikipedia description of these methods at: **http://en.wikipedia.org/wiki/Window_function**

The behaviour of some common windows is shown here, in images taken from that article. In each case, the left panel shows the function by which the input time-domain samples are multiplied. On the right is the sample output of an FFT for a pure sinewave with this windowing function applied. Note how slowly the function falls off from the peak with a rectangular window compared to the others.

For the task at hand, we decided to use Flat Top because this makes measuring the exact amplitude at a given frequency easy. Basically, it guarantees that even for frequencies which fall between two 'bins', one of the bins will contain the correct value. The other will contain a similar or lesser value. This means we don't have to do any complex summing to determine fundamental or harmonic amplitudes. For an explanation, see: **www.dsprelated.com/showarticle/155.php**

However, Flat Top has worse frequency resolution than most other windowing methods since the harmonics are spaced apart nicely (by the fundamental frequency in fact), it isn't really an issue.

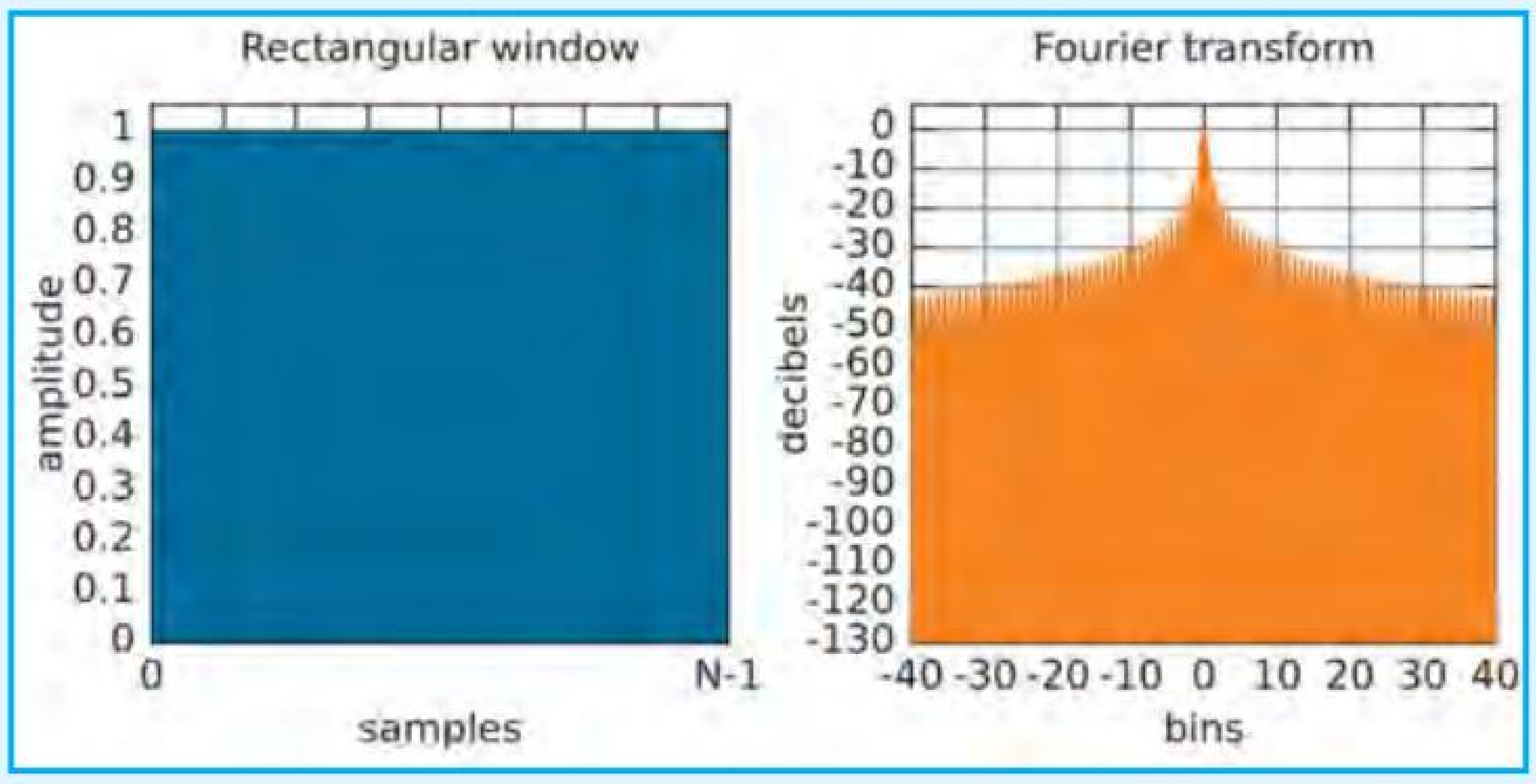
But there is another, more subtle (and less discussed) issue with windowing and this is that it also causes the resulting amplitudes to fall off at higher frequencies. Failure to compensate

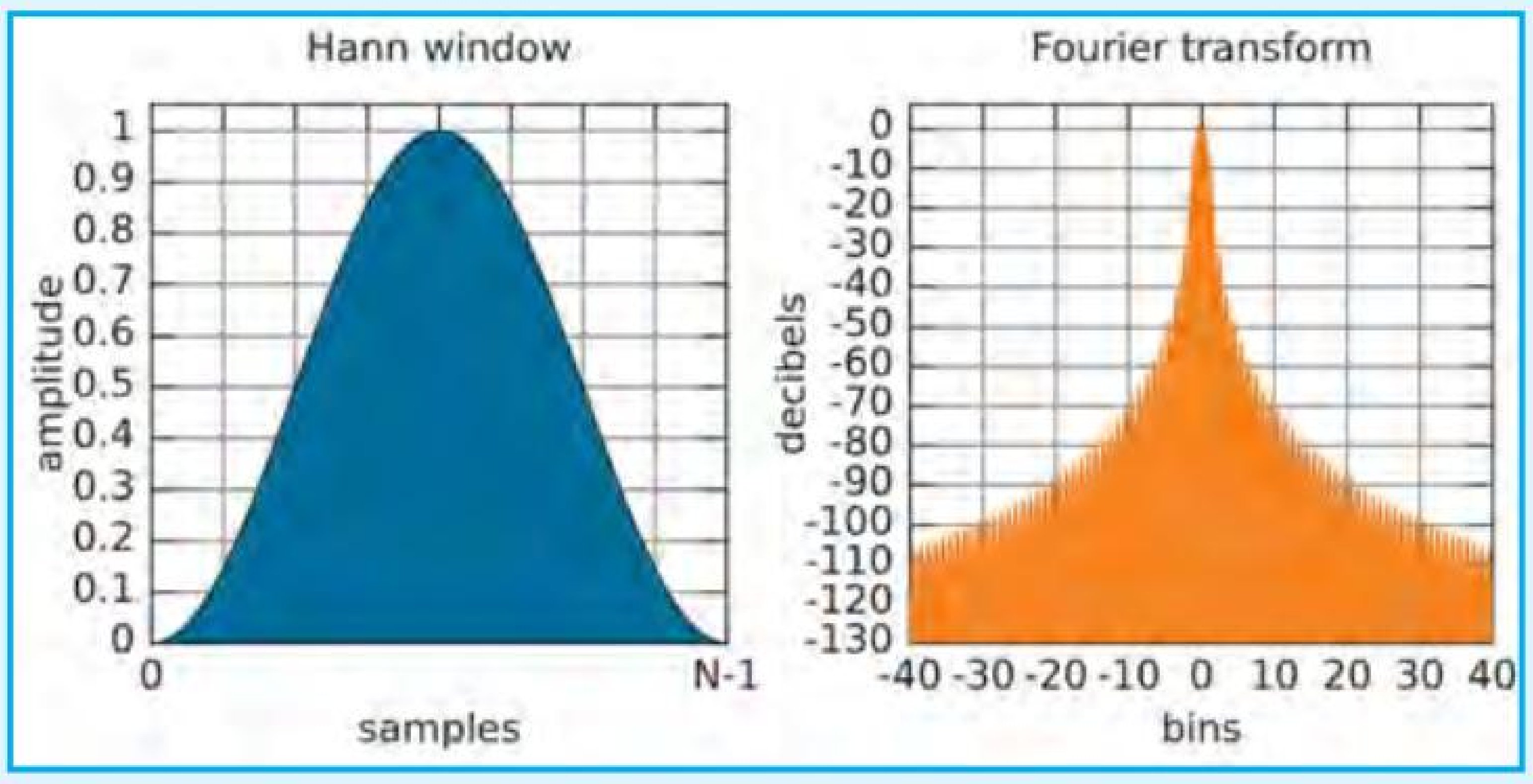
Testing

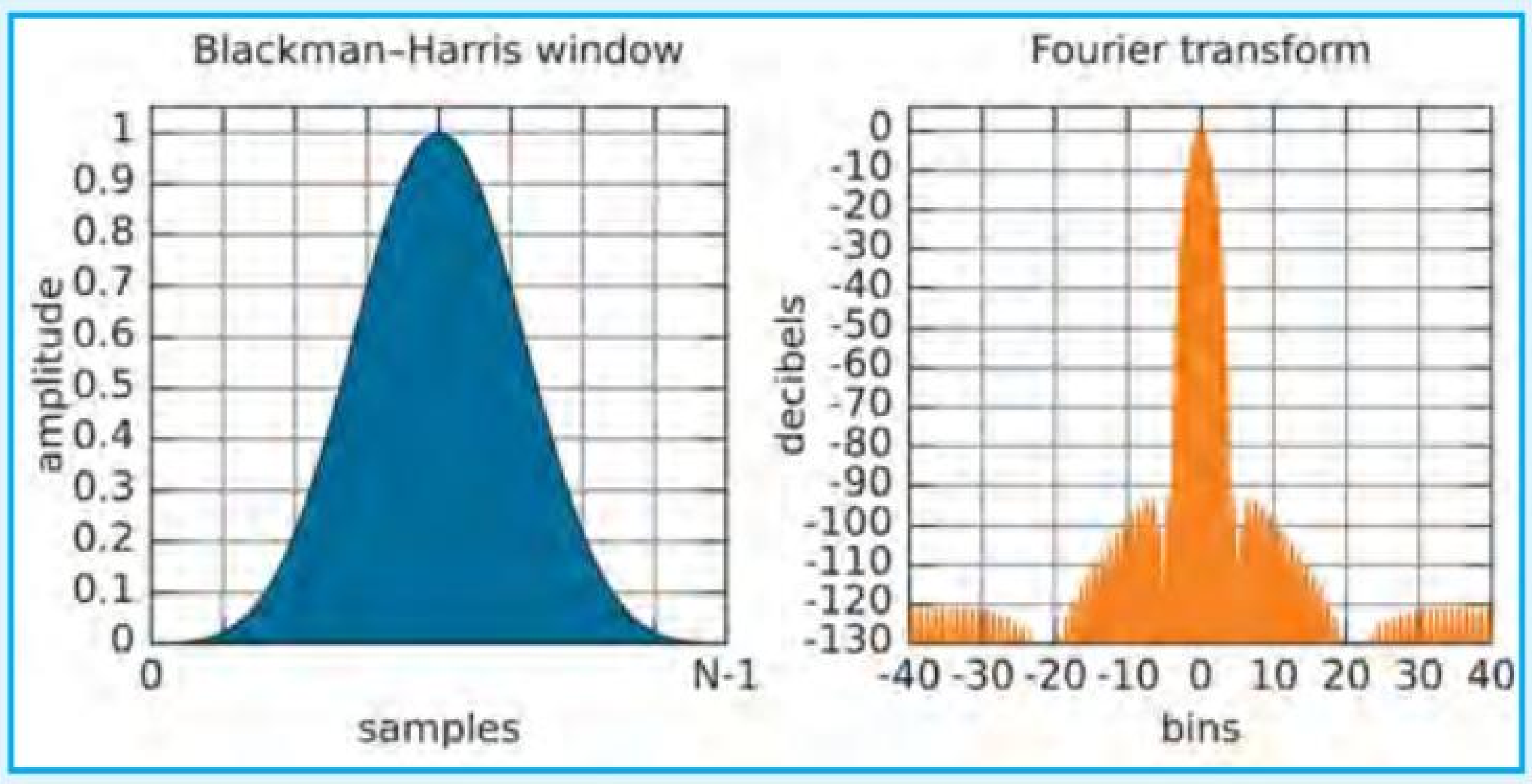
If you have a triangle-wave generator, you can test the unit quite easily. First, turn trimpot VR1 fully anti-clockwise and apply the triangle-wave to CON2 with a peak-to-peak voltage close to 5V if possible. That done, apply power, switch S1 to position 2 and turn VR1 clockwise until either LED2 lights or you reach the end-stop. If LED2 lights, turn VR1 anti-clockwise until it just turns off.

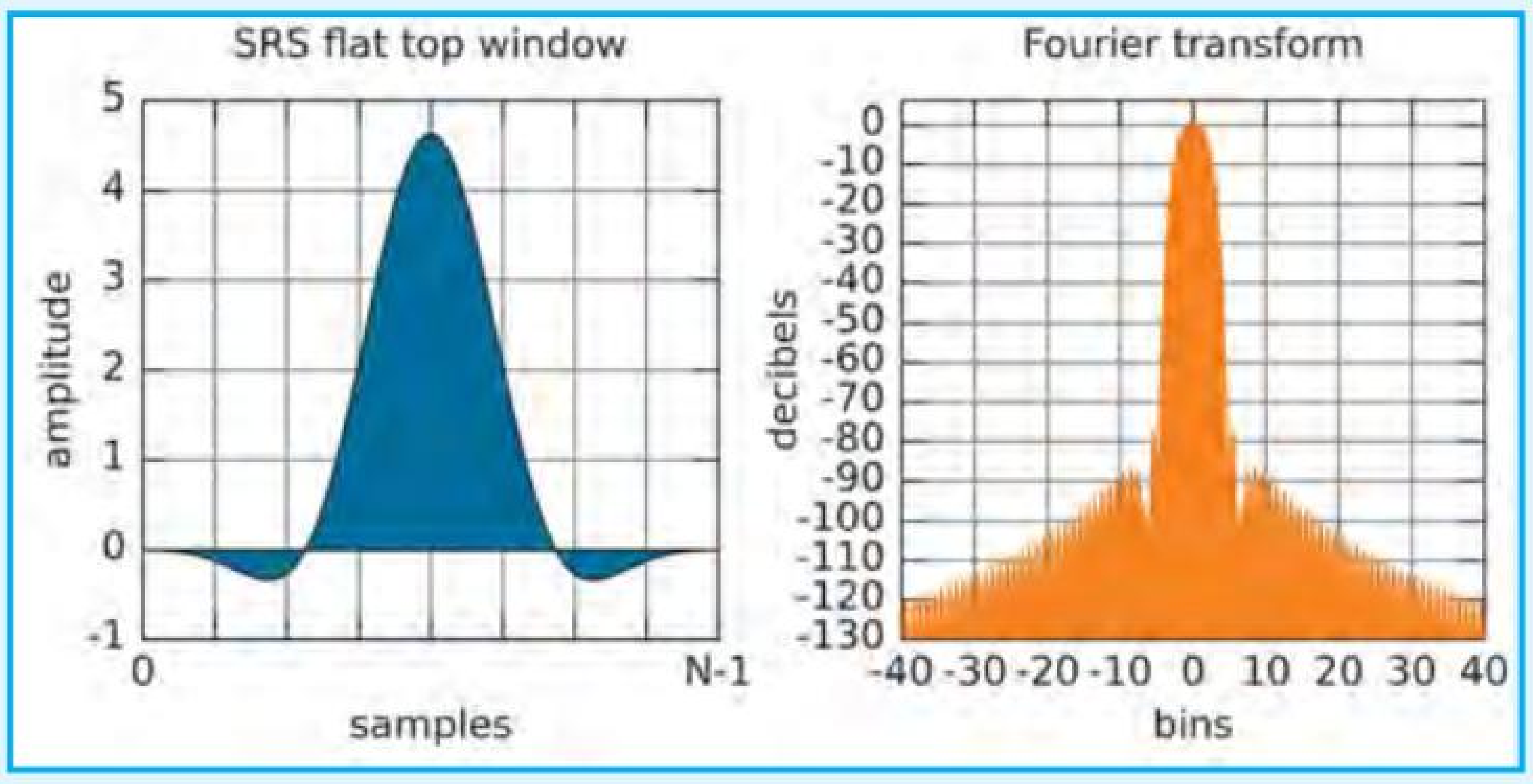
Now measure between TP1 and TP2. It may take a little while to settle, but it should give a reading close to 1.2V (representing 12% distortion) and stay there. However, it may be slightly higher if your triangle-wave source is badly distorted. LED1 should flash at a few hertz, depending on the signal frequency (anywhere in the range of 20Hz-10kHz should be OK).

If you don't have a suitable signal generator, you can use the same procedure with the signal fed in from a 9-12VAC plugpack instead. Expect a reading of around 300mV, ie 3%.









for this will cause under-estimation of distortion due to apparently reduced harmonic amplitudes.

Our simple solution to this problem was to run a Flat Top-windowed FFT on a series of sinewaves of equal amplitude, each of which was at a frequency centred on a bin, measure the resulting peak value and store its inverse in a correction table. By then multiplying the output of the FFT by this correction table, we cancel out the frequency-dependent windowing attenuation.

Having sampled the data, applied the windowing function, performed the FFT and determined the fundamental frequency, we then look for the second harmonic at twice the fundamental frequency. We handle cases where the fundamental falls between bins using an estimation function. Normally, there will be a small but definite second harmonic spike and we then look at a 50% higher frequency for the third harmonic and so on. Each harmonic spike that is found improves the accuracy of the guess for the location of the next harmonic.

It's then just a matter of summing the squares of the resulting amplitudes, then dividing this by the amplitude of the fundamental and performing a square root to give the THD result.

Improving efficiency

We said above that the input to an FFT is normally a set of complex numbers with zero imaginary components. Our FFT algorithm is a 32-bit fixed-point in-place calculation with a 4096 window size. This means the input is 4096 × 32 × 2 bits (two 32-bit numbers for the real and imaginary part of each complex number), for a total of 32KB storage required. Our micro has 64KB RAM, leaving half for other stuff.

Here the advantage of the in-place FFT becomes apparent; because the same buffer is used as the input and output and no temporary storage is required, we can have a larger window size than would otherwise be possible.

But it's actually possible to double the effective window size to 8192 samples without using any extra RAM. How you ask? Well, have a look at this explanation from Texas Instruments: **http://processors.wiki.ti.com/index.php/Efficient_FFT_Computation_of_Real_Input**

To start off, what you do is take your 8192 samples and create 4096 complex numbers where the real and imaginary part of each consists of alternating sample values. Thus, the imaginary portions aren't 'wasted' by being filled with zeros. You then perform a normal FFT computation.

Normally, half of the FFT output is 'wasted' as the second half is identical to the first half (but reversed in order). With this method, the extra data is no longer duplicated and by convolving it with some sinewave coefficients, using the formulae provided by TI, we recover the full set of result vectors that we would have gotten with a twice-as-large window with a regular FFT.

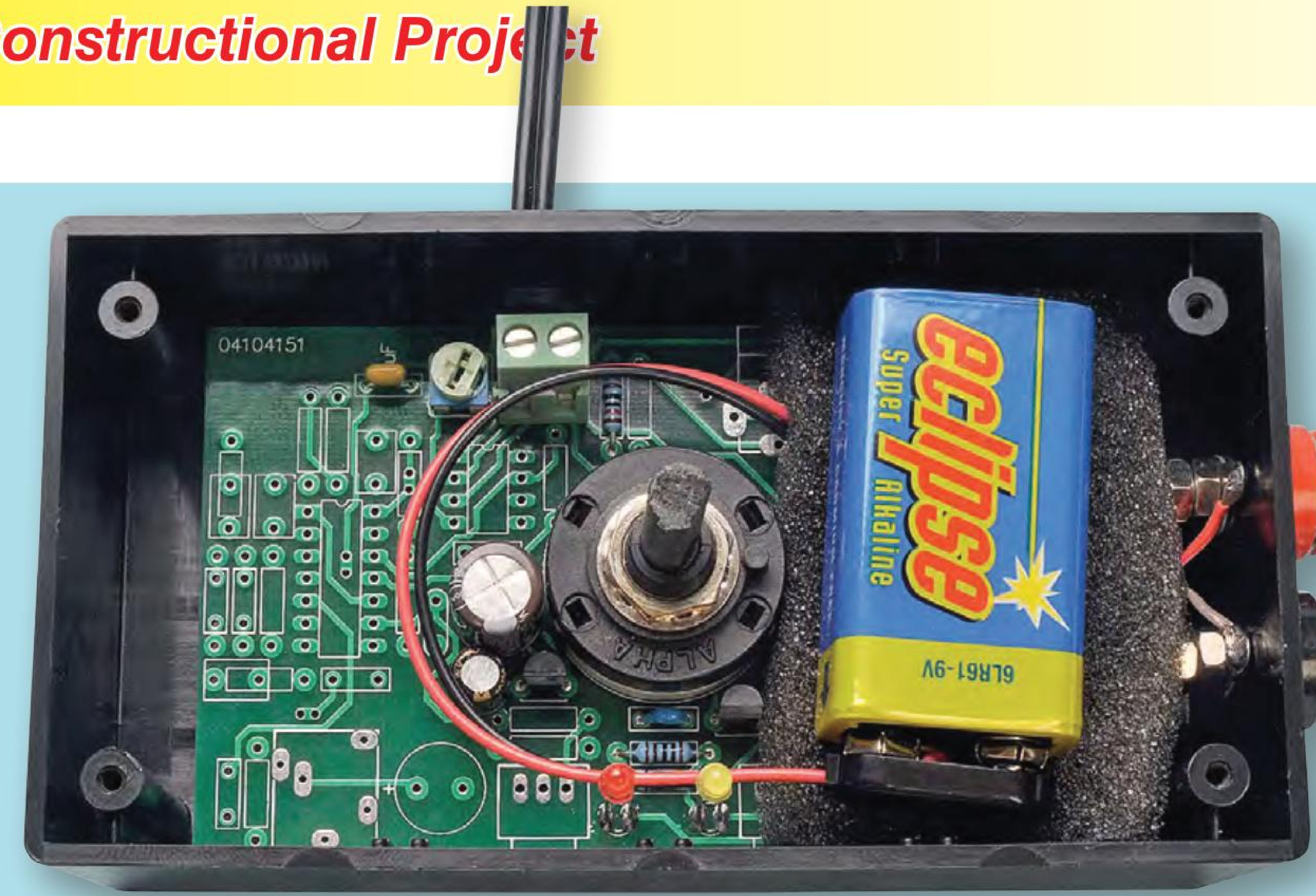
Don't worry too much about understanding the mathematics behind this – it certainly works!

If LED1 doesn't flicker or the reading seems wrong, switch off and check for circuit faults. Assuming it's all OK, you can optionally do a further test if you have a sinewave generator. Apply its signal to CON2 using the same procedure as above and you should get a low voltage reading at TP1 of around 30-100mV, representing the lower limit of the distortion measurement – 0.03-0.1%, depending on how pure the sinewave is.

Note that if the unit can't find a signal at all, the output voltage goes to 0V. This will be the case if the input signal amplitude is too low, given the setting of VR1. If a signal is detected but it is grossly distorted (eg, a square wave), then the output will peg at 3.3V.

Putting it in a box

If you're planning on building the unit into the recommended UB3 jiffy box, it will snap into the integral ribs. All that's required is three holes in the lid for S1 and the two LEDs, plus some



This is the view inside the completed instrument. The PCB snaps into integral plastic ribs inside the case, while the battery is sandwiched between a piece of foam and the case lid as shown.

holes in the base for the signal input and output.

For the lid, copy the front-panel label shown in Fig.4 and use this as a drilling template. You can then download the label in PDF format from the *EPE* website, print it out, laminate it and glue it to the lid. The holes can be cut out using a sharp hobby knife.

For the signal input, we drilled a hole adjacent to the location of CON2 and fitted a small rubber grommet. We then cut away a section of the grommet on the inside of the case so that the PCB would still fit properly (you probably don't need a grommet; we just wanted to make sure the leads don't fray from rubbing on the edges of the hole).

For the output, we drilled two holes 19mm (0.75-inch) apart at the right-hand end of the box (centred on that end). We then fitted binding posts and soldered two strands of ribbon cable to the binding post lugs. The other ends of these leads were then soldered to TP1 and TP2.

After passing the signal cable through the grommet and screwing it firmly into CON2, we dropped the board in the box, placing some non-conductive foam next to S1 (either side will do), connected the 9V battery and sat the battery on top of the foam. The lid was then attached, which holds the battery in place and the knob is secured to S1's shaft.

Using it

There isn't much to it, simply connect a 3-20VAC signal source (eg, an AC plugpack) to the signal input leads and turn S1 to its first stop, for the full THD measurement. Use a small flat-bladed screwdriver to readjust the sensitivity control if necessary, then connect the outputs to a DMM and calculate the distortion by dividing the voltage reading by 10 to get the percent figure. For example, a reading of 0.28V indicates 2.8% distortion.

If you want to use the device for measuring audio signals, you may wish to reduce the 10kΩ resistor value at the top of VR1 – however, it should not go below 470Ω (higher, if you will be probing signals above 20V peak). This is to protect IC1 from excessive current flow. In this case, you may wish to connect some sort of probe or clip leads to CON2.

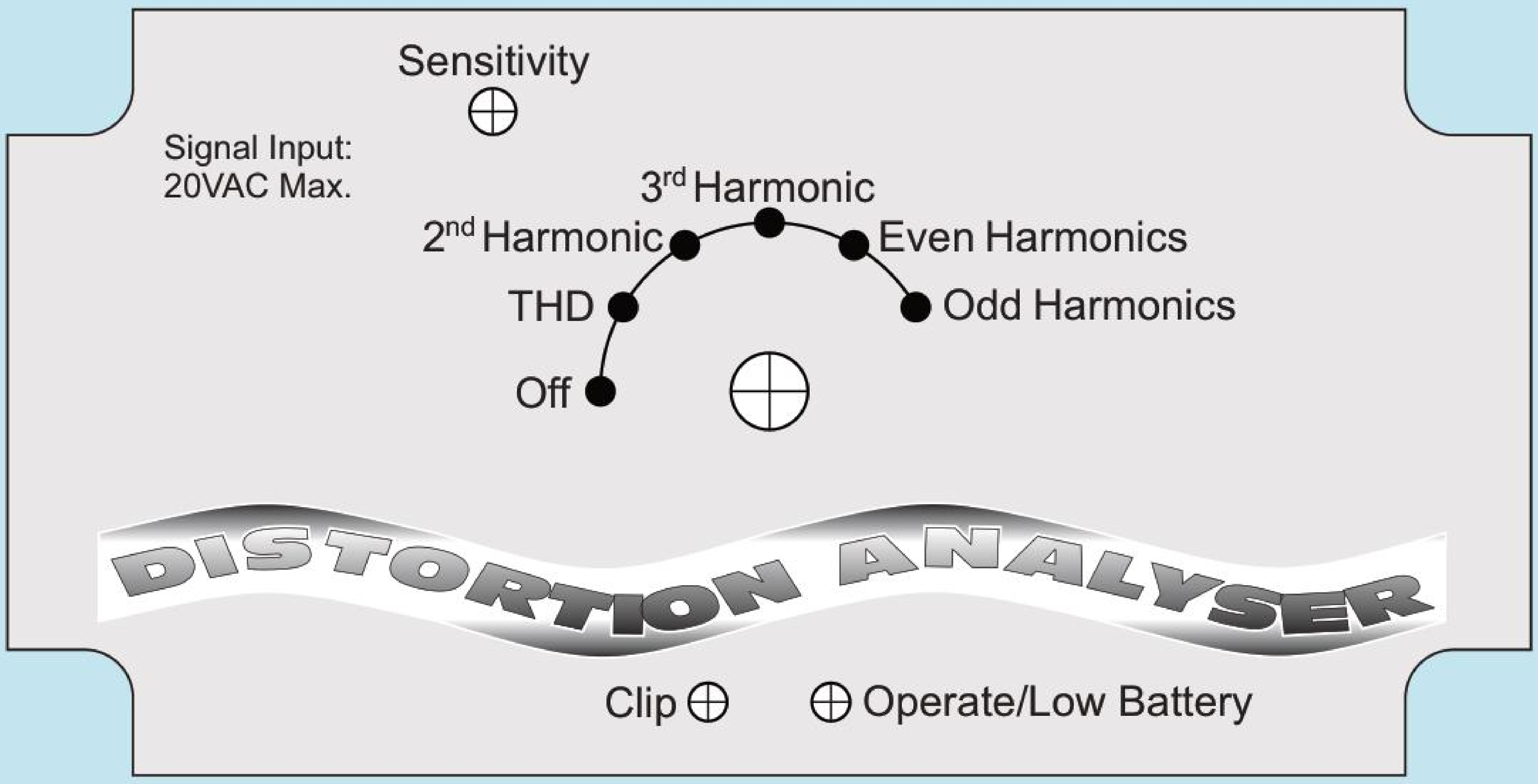


Fig.4: top lid label for the UB3 jiffy box. To make a reading, connect the signal up and simply rotate the knob to the required position. The output voltage will stabilise after a few seconds, once the unit has adjusted for the signal frequency and the output filter capacitor has finished charging.

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EVERYDAY PRACTICAL ELECTRONICS is offerring its readers three chances to win a Microchip Curiosity Development Board! This board is a cost-effective, fully integrated 8-bit development platform targeted at first-time users, makers and those seeking a feature-rich, rapid prototyping board.

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Curiosity is the perfect platform to harness the power of modern 8-bit PIC microcontrollers. Its layout and external connections offer unparalleled access to the Core Independent Peripherals (CIPs) available on many newer 8-bit PIC MCUs. These CIPs enable the user to integrate various system functions onto a single MCU, simplifying the design and keeping system power consumption and BOM cost low.

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Got a boat, van, 4WD, recreational vehicle... need a light? Need Light?

Really Bright 12/24V LED Oyster Light

By Ross Tester

Here's a low-cost, 1000+ lumen, attractive 'Oyster' LED light fitting for when you don't have mains available. Or even if you do! It runs from 12-24VDC or even from 230VAC with an optional (low cost) mains adaptor.

Here's a low-voltage LED-based light fitting which is ideal for boats, caravans, recreational vehicles and mobile homes, trucks, 4WDs . . . in fact, anywhere you have 12-24V DC available.

And it could also be used as a mains-powered LED light with a low cost, optional AC adaptor (albeit with a bit of fiddling).

There's virtually nothing to build with this one. The Oyster-style lamp housing is already fitted with a PCB containing 24 ultrabright, pure white LEDs in two concentric rings, connected in series/parallel.

In the centre of these is a driver PCB which supplies the 40V @ 260mA required by the LEDs

Overall current drawn from a 12V supply is around 1.1A, dropping to about 550mA from a 24V supply.

Light output from the Oyster fitting is more than 1000 lumens. Looking directly at it, you'd swear it was a lot more!

For comparison, a traditional 36W fluorescent tube puts out about 3500 lumens, but that's over a much wider length.

Oyster size is about 260mm diameter × 75mm deep, so it's not too dissimilar to other domestic light fittings. An integral 235mm diameter aluminium backing plate/heatsink is designed to be screwed to a ceiling, wall or bulkhead, and the Oyster diffuser mounts on that via a twist onto three pins.

Now a quick word to the wise: the diffuser is made of quite thin (and somewhat fragile) plastic so if you go at it like a bull at a gate, you're liable to put your thumb or fingers right through it (we speak from experience.

When disassembling, which is simply a matter of turning the diffuser with respect to the base, treat with a bit of care!

The LED driver

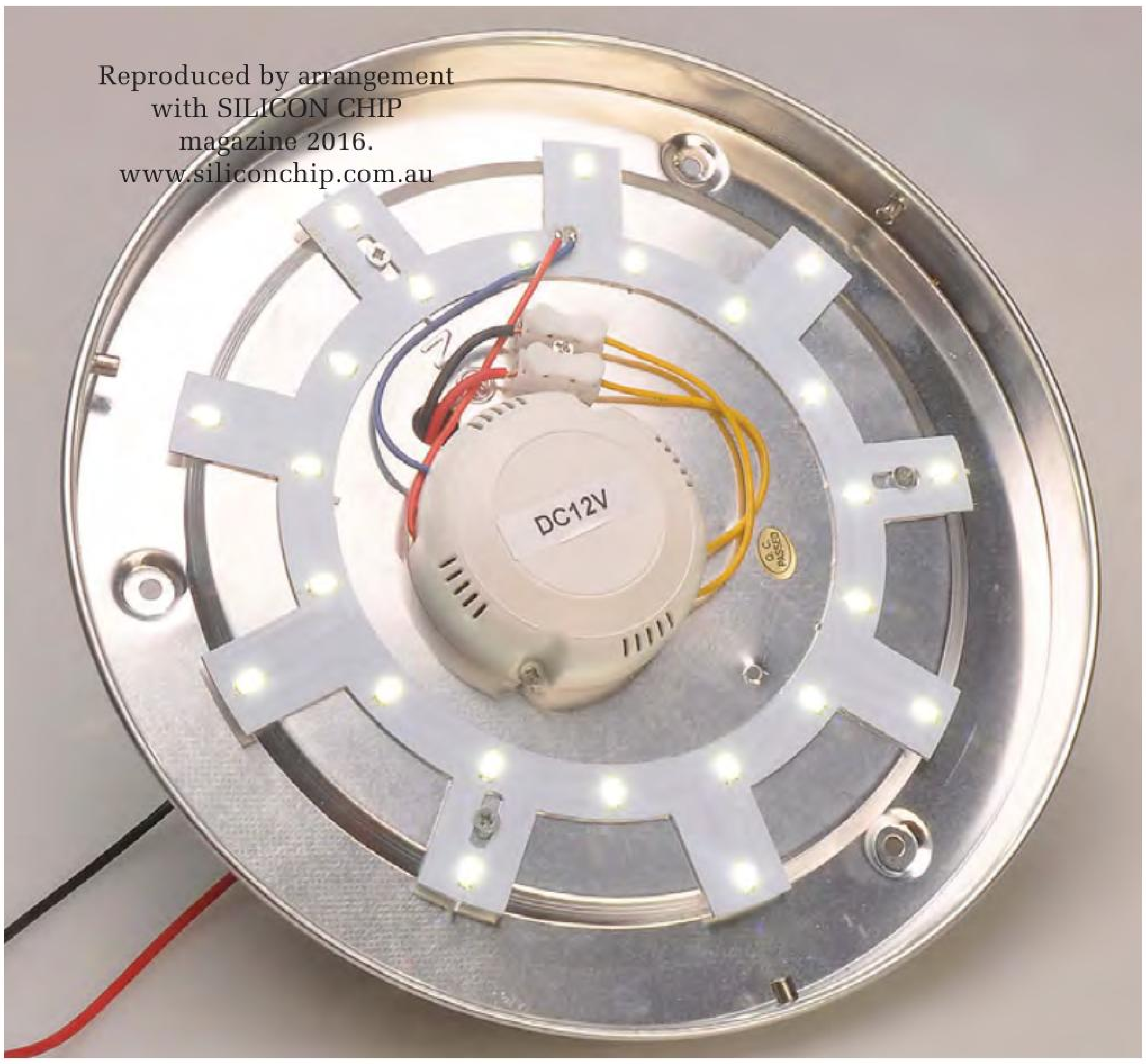
The driver PCB circuit is shown in Fig.1. You don't need to worry about the polarity of the DC supply as this is taken care of by a bridge rectifier at the input.

However, this results in a not-so-insignificant voltage drop across the two bridge rectifier diodes (2 × ~0.6V or about 1.2V).

Therefore, you're effectively throwing away 10% if it is a 12V supply.

Directly feeding the filter capacitor (C1) rather than through the bridge would be more efficient, albeit at the expense of the reverse-polarity protection provided by the bridge.

If you wanted to, you could feed the circuit with AC (obviously via the bridge) – say from 8 to 18V. However, this would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24 ultra-high-brightness white LEDs are powered by an integral 12/24V driver (ignore the DC12V sticker!). The backing hardware also doubles as an LED heatsink.

require a much larger 'filter' capacitor – the existing one is 100µF; you would need at least ten times this for AC (preferably more – 2200µF or 3300µF would not be too much if it woud fit). This capacitor is bypassed by 100nF.

Power is applied directly to inductor L1 and IC1, a 60V, 4A switching current boost LED driver.

Inside IC1 is a switching MOSFET which turns on and off at about 180kHz. Every time it turns off, the magnetic field built up in L1 collapses, inducing a higher voltage at the anode of diode D5.

This is rectified by D5 and stored by capacitor C3/C4. Ordinarily, this voltage could be quite high, but is limited to 56V by zener diode ZD1 (IC1's maximum voltage is 60V). If the voltage across C3/C4 exceeds 56V, the Zener conducts and stops the inverter by applying a voltage to IC1's feedback pin (pin 5).

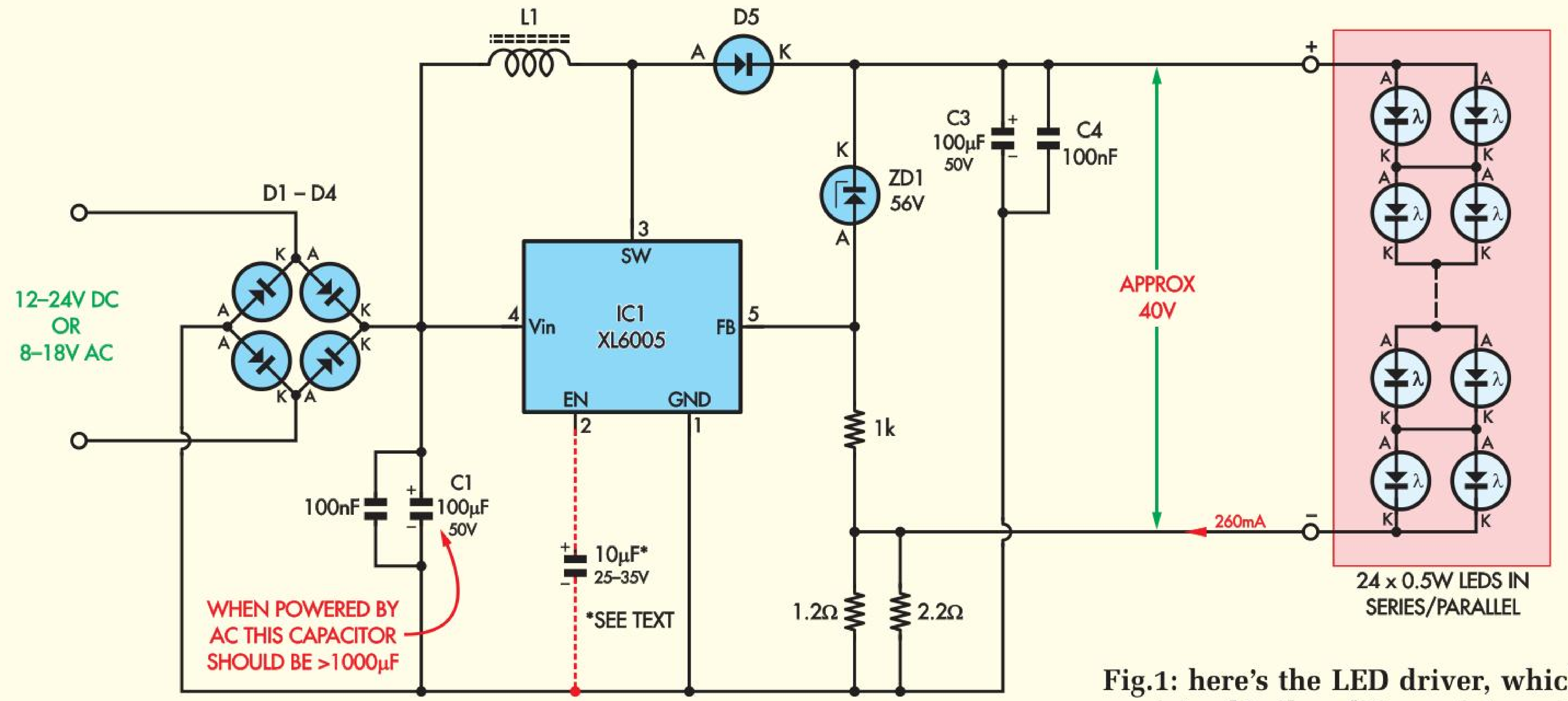
The output voltage is further clamped to approximately 40V by the 24 high-brightness LEDs connected in series/parallel at the output. Effectively, there are 12 LEDs in series, each dropping about 3.3V (12 × 3.3 ≈ 40V).

The voltage at the feedback pin of IC1 (pin 5) controls the duty cycle of the MOSFET, while pin 2 (the enable pin) can be shorted to ground to stop the inverter working. We use this pin to allow it to 'soft start' the inverter so it can be used with a switch-mode supply, as detailed shortly.

Operating on 230VAC

Oatley Electronics have a very-low-price switch-mode power supply (KC24) which can deliver 24V DC at up to 1A. At first glance, this would appear to be ideal for powering the Oyster LED light from the mains. Unfortunately, appearances can be deceiving!

By its very nature, the Oyster LED lamp has quite a high surge current at


L1
D5
A
K
+
C3
100µF
50V
C4
100nF
K
ZD1
56V
A
D1 – D4
K
A
3
SW
12–24V DC
OR
8–18V AC
4
Vin
IC1
XL6005
FB
5
APPROX
40V
EN
GND
2
1
1k
100nF
C1
100µF
50V
10µF*
25–35V
*SEE TEXT
WHEN POWERED BY
AC THIS CAPACITOR
SHOULD BE >1000µF
1.2Ω
2.2Ω
260mA
–
λ
24 x 0.5W LEDS IN
SERIES/PARALLEL

LED OYSTER LIGHT DRIVER (OATLEY ELECTRONICS)

Fig.1: here's the LED driver, which is contained in the white container at the centre of the photo above. It supplies around 40V DC @ 260mA from a low voltage DC or AC source.

Oatley's KC24 230V to 24V @ 1A switch-mode power supply. It's suitable for use with the Oyster LED light, but requires a small modification, as described in the text to stop the power supply shutting down at turn-on.

WARNING: 230V LED driver

An alternative 230V AC LED driver (285MACC) is also available but **WE STRONGLY RECOMMEND THAT YOU DO NOT USE THIS DRIVER**.

It is **not an isolated supply** so the whole LED mounting base can become live – indeed, we checked this driver with the Appliance Insulation Tester described elsewhere in this issue and it instantly tripped it (ie, isolation <700kΩ.

Stick to the **SAFE** 12/24V LED driver and if you want to run it from the mains, use the KC24 switch-mode supply as detailed above. Incidentally, we checked the KC24 supply with the same tester and it passed with flying colours.

switch-on, which is enough to trip the over-current protection circuitry in the KC24 supply, which turns off almost straight away. The high surge current disappears, the power supply again tries to start, resulting in a high surge current... you get the picture!

The result is that the Oyster LED Lamp 'strobes' – a neat feature if you're having a party, but not quite so good if you're looking for good illumination.

The KC24 power supply is sealed, so no adjustment is possible there (not that we'd want you to because it is a mains-powered device and can therefore 'bite' very hard).

But it's easy enough to open up the LED driver in the Oyster LED Light and modify it slightly so that it 'soft starts', eliminating that surge current.

All you need do is insert a small (say 10µF) capacitor in series with the 'enable' pin of the IC, which introduces a delay of a few seconds before operation is enabled. In fact, if you buy the Oyster LED light and power supply kit from Oatley Electronics, they will include a 10µF, 35V electrolytic capacitor for this purpose.

You'll need to lift the enable pin (pin 2) off the PCB. It's not hard to do this as it is a surface-mount device – melt the solder with your soldering iron and use a hobby knife to prise the pin up, ensuring you've removed all the solder underneath (solder wick is handy for this).

Now solder the positive lead of the capacitor to the pin (not the PCB!) and the negative lead to a suitable earth point – we used the top end of resistor R3, as shown in the photo. That's all there is to it.

Power supply connections

Power wires, either 12-24V DC or 8-18V AC go through a hole in the back of the Oyster LED light, very close to the push-button terminal block. As we mentioned before, you don't need to worry about polarity, so simply connect either wire to either terminal.

Mains supply

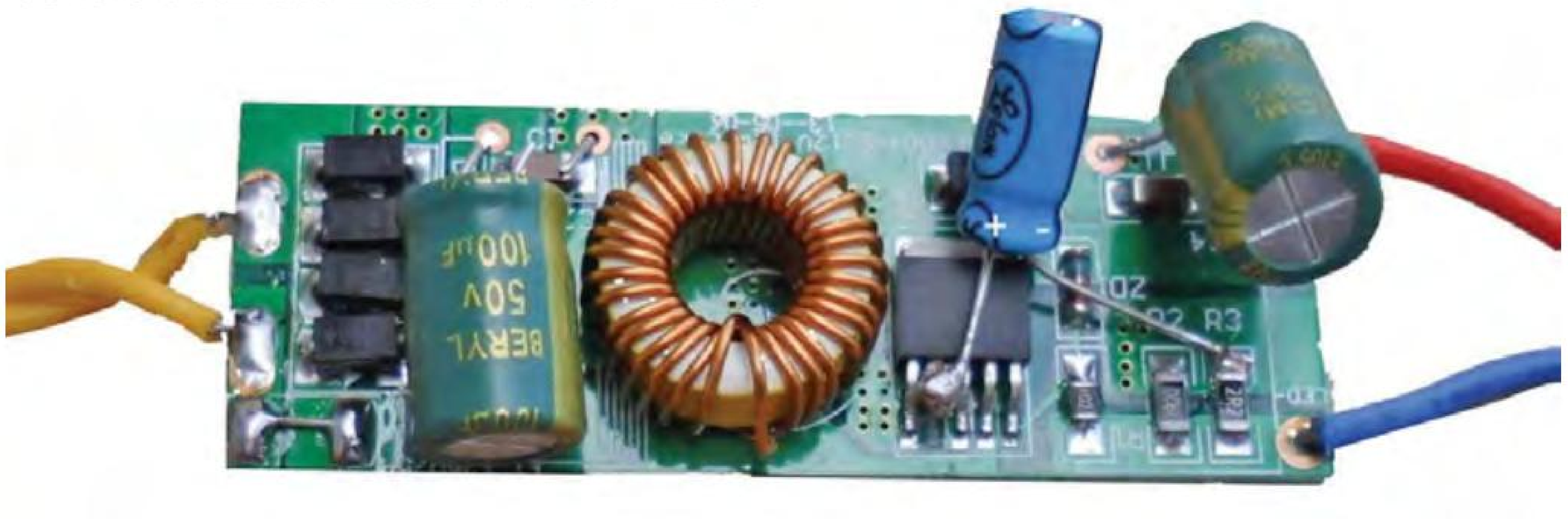
The KC24 power supply from Oatley comes with a short length of mains cable, fitted with a 'figure 8' plug on one end (the end which plugs into the supply). The opposite end is bare – you'll need to fit it with a standard mains plug.

Make sure you connect the two leads to the live and neutral terminals in the plug – they're either labelled 'A' (for active, ie 'live') and 'N' or in some cases colour coded, usually red (live) and black (neutral). In newer plugs, the colour coding may conform to the IEC colours of brown (live) and blue (neutral).

Do **NOT** connect anything to the plug's earth terminal ('E', green or green-gold) and make sure that you slide the rear cover all the way onto the plug body.

The DC end will probably have a 4-pin DIN plug on it, which has to be cut off. Stripping the outer insulation back will reveal four wires – red and black (positive) and green and white (negative). **Note that – the black wire is definitely positive – it's a trap for young players**.

You only need to use one pair of wires (ie, there's no need to parallel them), say the red and the green wires, for DC out. These go through the hole in the back of the Oyster LED light to the push-button terminal block. As we mentioned before, you don't need to worry about polarity.



Here's that modification required for the LED driver – a 10µF capacitor is added in series with the 'enable' pin of the IC to slow its start. This prevents it overloading the power supply and shutting it down. The PCB first meeds to be removed from the white housing in the middle of the LEDs.

Where from, how much?

The LED Oyster Light is available from Oatley Electronics, PO Box 139, Ettalong Beach, NSW 2257; phone [02] 4339 3429 (www.oatleyelectronics.com).

On its own, the LED Oyster Light as described here (with 12/24V LED driver) sells for $25.00, inc. GST, (Cat No K400). The KC24 230V AC to 24V DC switch-mode supply sells for $9.95 inc. GST.

However, at the time of writing Oatley Ekectronics are selling BOTH the LED Oyster and switch-mode supply for just $28.00 (Cat No K400P1), inc. GST.

And if you want two sets, the price reduces to only $50.00 for both inc. GST (Cat No K400P2). All prices are plus freight.

Orangepip

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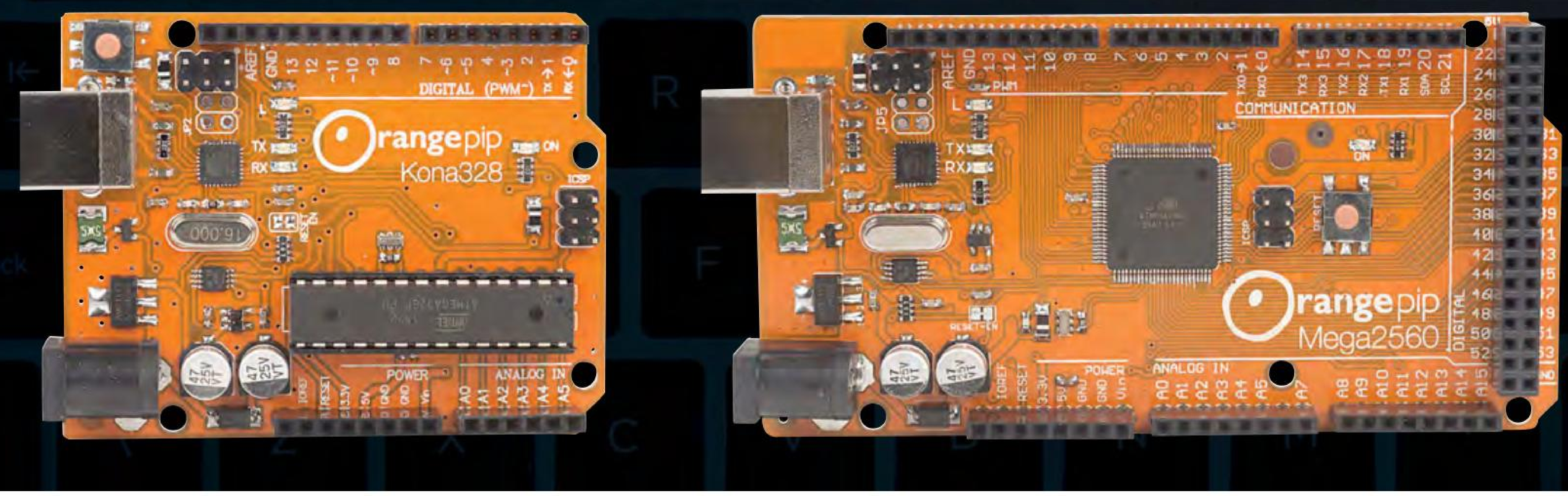

WHAT IS ORANGEPIP?

See your projects grow with Orangepip – a distinctive new range of open source boards which offer a colourful introduction to coding and prototyping. Based on the ATmega2560 and ATmega328 microcontrollers, the Orangepip boards are fully compatible with Arduino shields, sensors, accessories and software – giving users access to the global Arduino community of makers and projects.

The boards themselves are rich with features, including 16MHz oscillator, ATmega16u2 for serial conversion, 14 digital GPIO I/O pins (Kona328) and 54 I/O pins (Mega2560), quick reset buttons and machine screw holes. The high performance ATmega 8-bit AVR RISC-based microcontrollers give Orangepip users enough power and memory to store and run multiple lines of complex code.

Kona328

The Orangepip Kona328 is an Arduino UNO compatible development board that is based around the ATmega328 microcontroller. The board features 14x digital I/O pins (six of which may be used as PWM outputs), 6 analog inputs and a 16MHz crystal oscillator. The board is simple to use, just requiring connection to a computer via USB to get started.

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Teach-In 2016

Exploring the Arduino

Part 3: Keypads, strings and displays

by Mike and Richard Tooley

AREF
GND
13
12
~11
~10
~9
8
7
~6
~5
4
~3
2
TX→1
RX←0
DIGITAL (PWM~)
L
TX
RX
SMD EDITION
UNO
ON
ARDUINO
ICSP
RESET EN
ARDUINO.CC
MADE IN ITALY
POWER
ANALOG IN
IOREF
RESET
3.3V
5V
GND
Vin
A0
A1
A2
A3
A4
A5

Welcome to *Teach-In 2016 – Exploring the Arduino*. This exciting new series has been designed for electronics enthusiasts wanting to get to grips with the immensely popular Arduino microcontroller, as well as coding enthusiasts who want to explore hardware and interfacing. So, whether you are considering what to do with your Arduino, or maybe have an idea for a project but don't know how to turn it into reality, our new *Teach-In 2016* series will provide you with a one-stop source of ideas and practical information.

In last month's *Teach-In 2016 Exploring Arduino* we looked at methods of connecting real-world hardware to the Arduino Uno. To this end, *Arduino Workshop* dealt with driving external loads, while *Arduino World* looked at some add-on interface boards that will allow you to drive high-current and high-voltage loads, such as mains-operated lamps and motors. *Coding Quickstart*, our regular programming feature, explained the structure and layout of program code as well as introducing decisions and how to make them. Finally, *Get Real* showed you how to design and construct a simple Arduino-based door/window security system.

This month

This month, we will be looking at some common types of display and indicator that the Arduino can use. In *Arduino Workshop* we will interface a low-cost LCD display, and *Arduino World* looks at keypads and buttons. Our programming feature, *Coding Quickstart*, introduces arrays, strings and string manipulation, plus some of the functions that you will need to manipulate characters and text. Finally, *Get Real* will show you how to use a low-cost matrix keyboard and LCD display to build a simple entry/access control system based on the Arduino Uno.

Coding Quickstart: Arrays and strings

Arrays provide us with a neat and efficient way of storing and accessing data. Array are groups of the same kind of data and, within the array, stored data is held in consecutive memory locations. This makes it easy and fast to access individual items (or elements) within the array. All we need to do is to index them to the start of the array. A simple example might be an array that stores the values assigned to the individual keys in a keypad.

An important feature of an array is that each element in an array is placed directly after the previous element. This allows us to use a simple loop to access the data. Each time we increment the index we arrive at the next element in the array.

To begin using an array we first need to specify the number of elements in it:

```
int e12series[12]; // an array with 12 integer elements
```

Notice how we've used square brackets to enclose the number of elements in the array. Each of these elements will be stored in consecutive memory locations, starting with the first element in the array and ending with the last element in the array.

Next we need to specify the variable that will be used as the index so that we can reference individual elements within the array:

```
int i;                // the array index
```

Now, to place some data in the array we will make each element equal to one of the E12 series of resistors, like this:

```
e12series[0] = 10;
e12series[1] = 12;
e12series[2] = 15;
e12series[3] = 18;
e12series[4] = 22;
e12series[5] = 27;
e12series[6] = 33;
e12series[7] = 39;
e12series[8] = 47;
e12series[9] = 56;
e12series[10] = 68;
e12series[11] = 82;
```

There's something important to note about this. The index of the first element in the array is zero, not 1. Similarly, the last index of the array isn't 12 (the total number of stored values) but one less than this, ie 11. We can access any element stored in the array by means of its index. For example, to access the fifth element in the array (which will have an index of four) we could use the following:

```
resistance = e12series[4];
```

To display each value in the series using the IDE's serial monitor we could use a loop, as follows:

```
for (i = 0; i < 12; i++) {
    Serial.println(e12series[i]);
}
```

Notice how `i++` post-increments the value of `i`, as explained last month.

Using 12 lines of code to place the data values into the array was a little cumbersome and there's actually a much better way of doing it, as follows:

```
int e12series[12] = {10, 12, 15, 18, 22,
27, 33, 39, 47, 56, 68, 82};
```

Successive values in the array are initialised using values from the list enclosed within the curly brackets. The first array element takes the value 10, the second 12, and so on.

Using this method, if you don't specify the number of array elements inside the square brackets the compiler will allocate storage based on the number of items that you've placed in the list. So we could, for example, have set up the array of E12 resistor values as follows:

```
int e12series[] = {10, 12, 15, 18, 22, 27, 33, 39, 47, 56,
68, 82};
```

Arrays are used in a number of applications. For example, Listing 3.1 shows a simple analogue monitoring application in which 60 values of voltage are read and stored in an array. For demonstration purposes we've used the Serial Monitor to view the data as it is collected and stored in the array. Note that the program will repeatedly collect sixty values, storing them in the same array each time.

You can use the excellent UnoArduSim (see Part 1 of *Teach-In 2016 Exploring the Arduino*) to test the code with analogue input pin-5 (A5) entered in the box that appears above one of the two analogue input voltage sliders. To display the values that are being stored in the voltage data array you can simply open the Serial Monitor window and watch them scrolling past. Altering the position of the analogue voltage slider should yield a range of input voltages from 0V to 5V, which will appear as data with values ranging from 0 to 1023.

Strings

Strings share many features in common with arrays. A string is simply a line of text where alphanumeric characters are represented by their ASCII values. Being able to handle and display simple text messages is important in a number of applications, such as displaying messages on an LCD screen or getting a password from a user.

String

A string can simply take the form of an array of characters. This must have a `char` data type and be terminated by an extra 'null' element to mark the end of the string. This has a value of zero. In 'code speak' this is referred to as a null-terminated string. An example is:

```
char stop[] = {83, 84, 79, 80, 0};
```

This produces the string 'STOP'. The null character at the end of the string simply acts as a terminating character when the string is read. The ASCII values for each character are stored in the individual elements of the array. A small but useful refinement is to store the characters rather than their code values, like this:

```
char stop[] = {'S', 'T', 'O', 'P', 0};
```

Even better would be to store the string as text enclosed in quotation marks, as follows:

```
String stop = "STOP";
```

Notice how we've been able to dispense with the curly braces and the null terminating code, but we've needed to use double quotes to enclose the text that we want to display. This third example uses a 'string object' and it provides you with an easy and powerful way of manipulating strings (but at the cost of using more memory space than a simple character array). However, for relatively small applications that don't use a great deal of memory, using the String object can save a lot of frustration.

Here are some things that we can do with the string object when we've constructed it:

```
// Print the string
Serial.println(stop);

// Change the string to lower-case
stop.toLowerCase();
Serial.println(stop);

// Overwrite string with another string
 stop = "Halt";
 Serial.println(stop);

// Get the length of the string
Serial.print("Length is: ");
Serial.println(stop.length());
```

Once again, don't be afraid to use the Serial Monitor in UnoArduSim to see how these string functions work.

Listing 3.1: Example of using an array in a simple data logging application

```
/* Using an array to store one minute's worth of data */

int voltageData[60]; // set up array for 60 voltage readings
int i;                // index into the array
int analogPin = 5;

void setup()
{
     Serial.begin(9600);  // to view the collected data
}

void loop()
{
     for (i = 0; i < 60; i++) {
          voltageData[i] = analogRead(analogPin);
          Serial.println(voltageData[i]);
          delay(1000);  // wait one second
     }
}
```

Arduino World: Keypads and buttons

Many simple interfacing projects require only a few buttons and switches for user input. Where that's the case you can use some of the Arduino's digital I/O pins configured as inputs using the simple techniques that you met in the two previous parts of *Teach-In 2016 Exploring the Arduino*. However, if you need to deal with quite a few buttons or switches things can get a little complicated and you can easily run out of digital inputs. That's certainly the case if you need to interface a keypad, but fortunately these are usually arranged in the form of a matrix of rows and columns requiring less of your precious I/O lines and leaving you more for other devices such as motors, relays and LCD displays.

Figs. 3.1 and 3.2 shows some typical low-cost matrix keypads suitable for use with the Arduino and other microcontrollers. They are both arranged as a 4 × 4 matrix; the keypad in Fig.3.1 uses a membrane, while that shown in Fig.3.2 is based on 16 individual push-button keys.

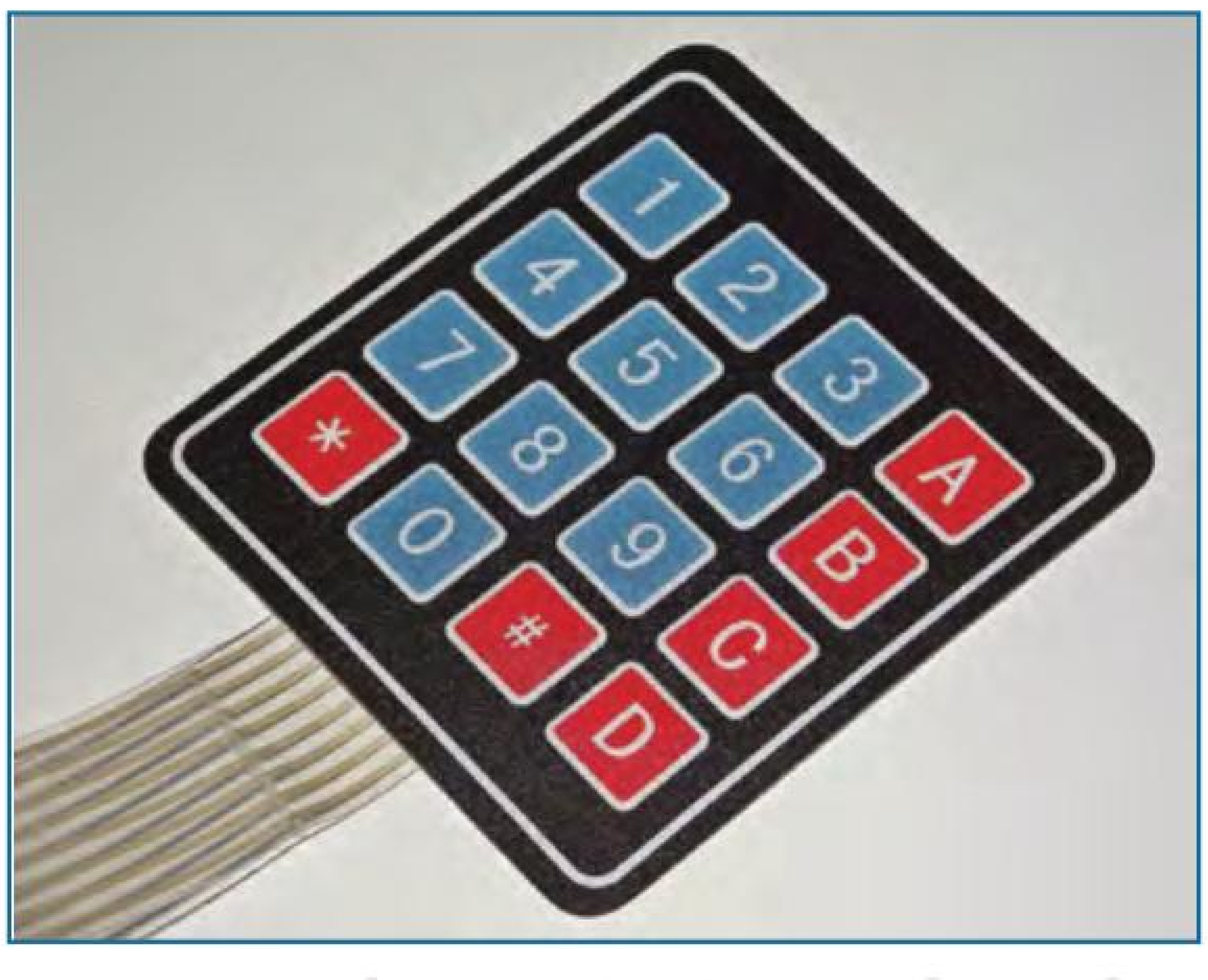


Fig.3.1. A low-cost 4 × 4 matrix keypad

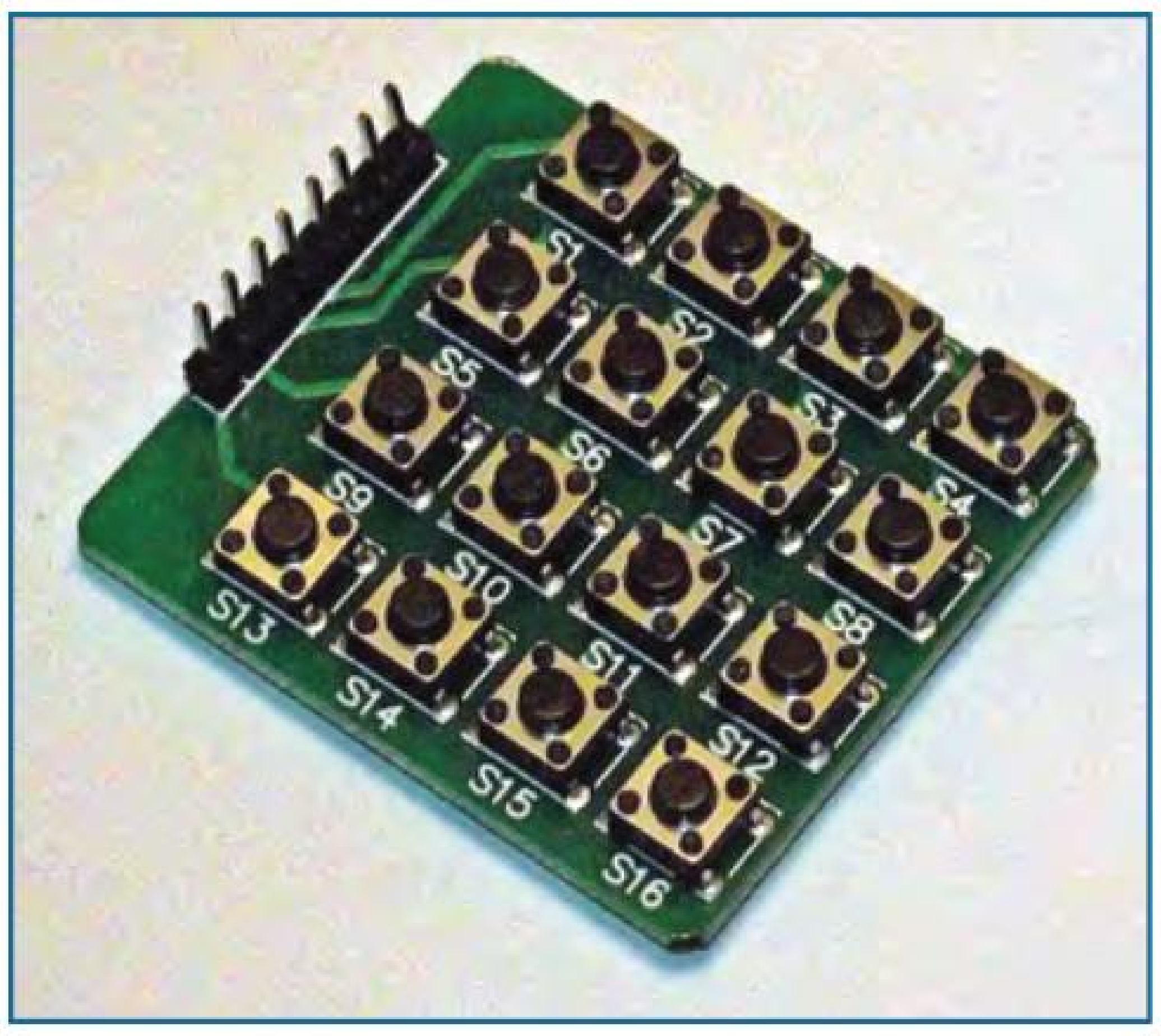


Fig.3.2. An alternative type of 4 × 4 matrix keypad based on individual button keys

Fig.3.3 shows the circuit arrangement of the 4 × 4 matrix keypad in Fig.3.1, and Fig.3.4 shows the pin numbering for the keypad's ribbon connector.

A 4 × 4 matrix keypad will give you a total of 16 keys to play with; 0 to 9 and A to D with additional * and # characters. The keys are placed at the intersection of the rows and columns so that, for example, when the A key is pressed the top row is linked to the rightmost column and consequently pins-1 and 8 will be connected together. On the other hand, if the key marked 9 is pressed pins-3 and 7 will be linked together. All we need in order to detect a keypress and decide which key is being pressed is some software that will drive the rows in turn and look for a signal returned on one or other of the columns. So, if pin-1 is taken high and a high is detected on pin-8 then we know the A key is being pressed. Similarly, if pin-3 is taken high and a high is detected on pin-7 then the 9 key is being operated. Fortunately, there's no need to write your own keypad code as someone has already performed this arduous task for you!

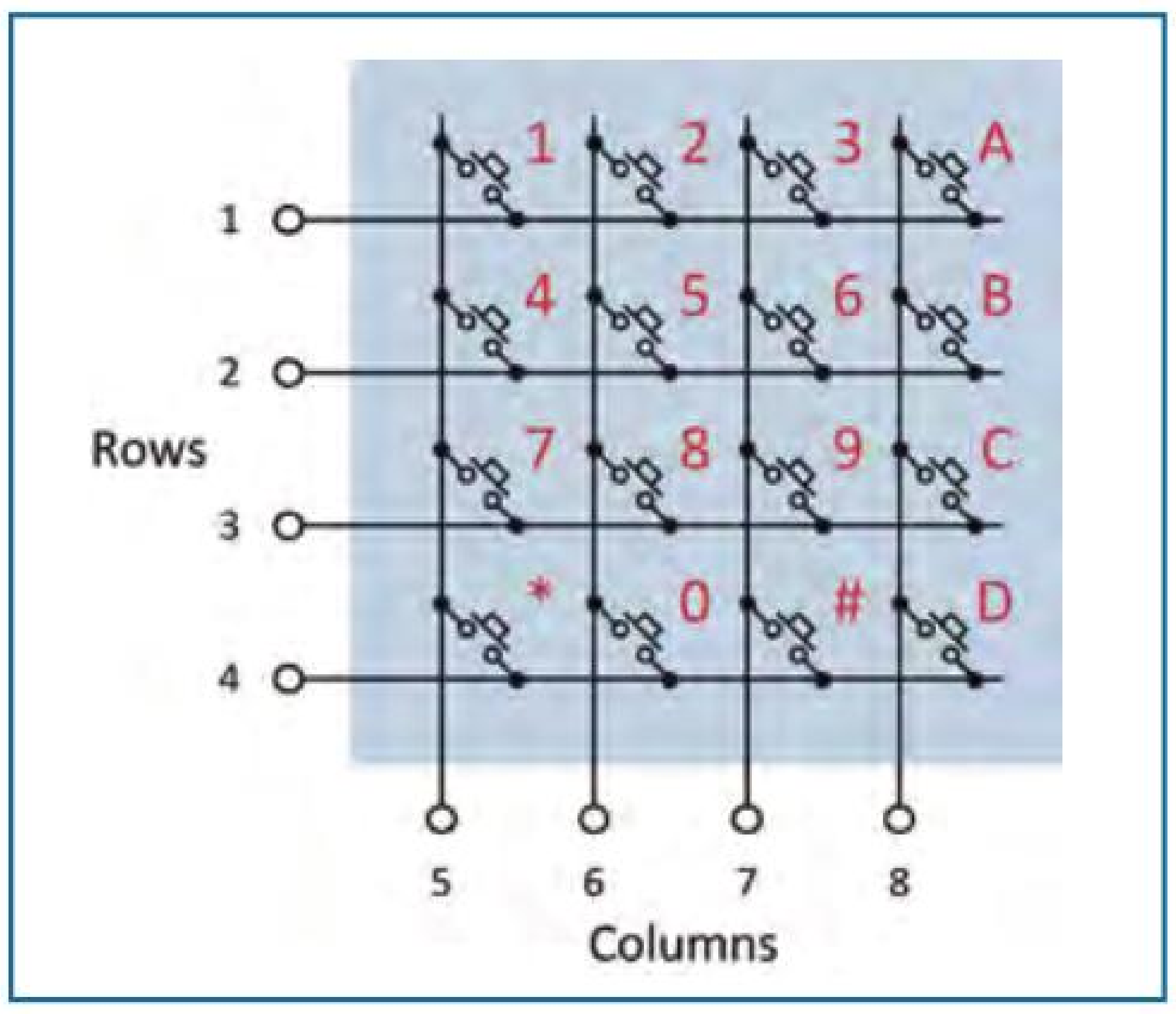


Fig.3.3. Wiring schematic for the 4 × 4 matrix keypad

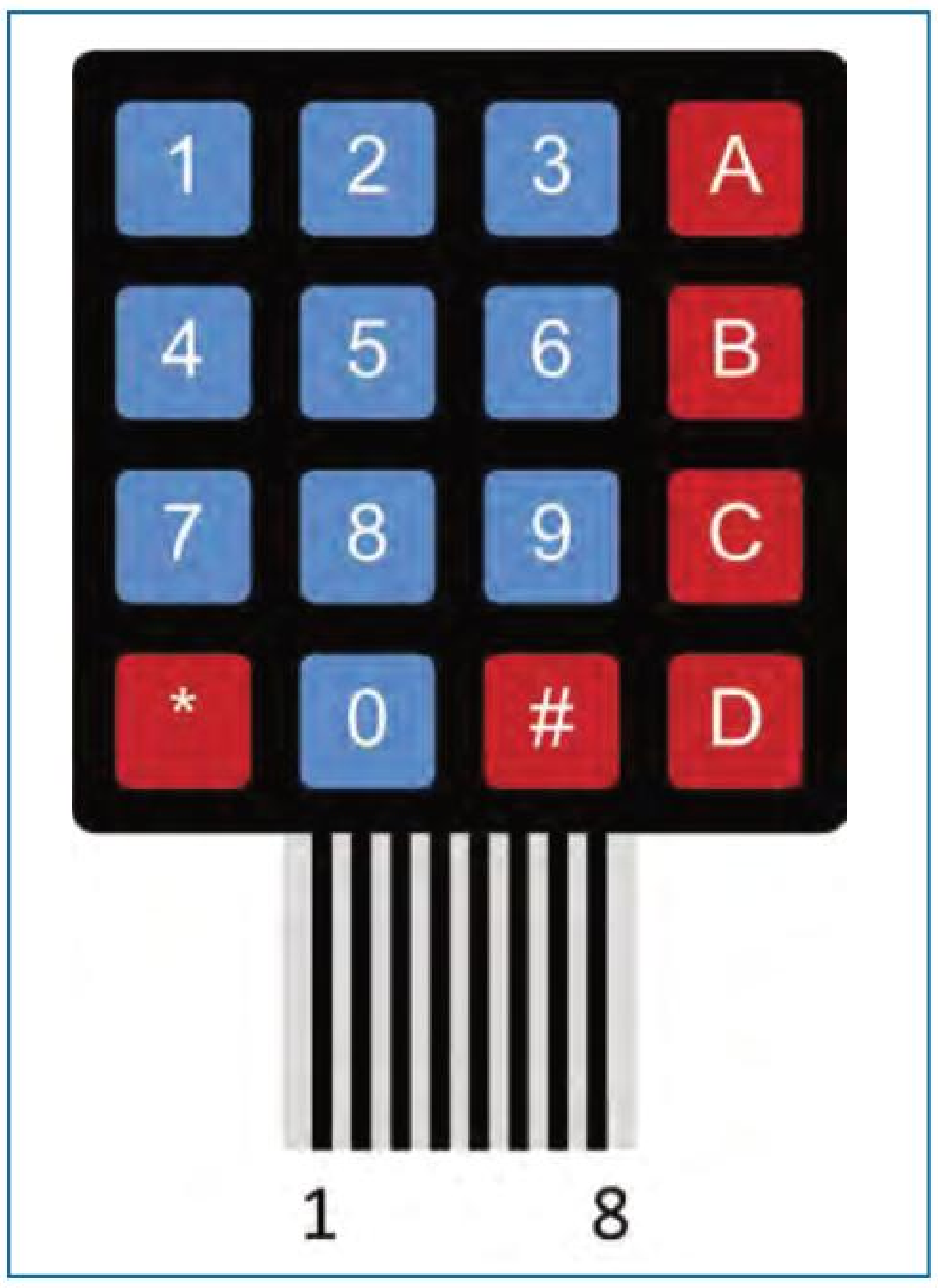


Fig.3.4. Pin connections for the 4 × 4 matrix keypad

Using libraries

Libraries can help you avoid the pain and long hours needed to develop, test and debug the low-level code required to interface external devices like keypads and LCD panels. Many libraries have been generously provided by enthusiasts who've made their work available for the benefit of the Arduino community as a whole, and the really good news is that you can quickly and easily import this code into your own applications using the Arduino IDE's excellent built-in library manager.

As well as the libraries that are supplied along with the IDE, there's a large number of additional libraries available on the web. To use these external libraries, you will first need to install them but the process is simple and straightforward as we will now explain.

Using the Library Manager

To install a new library into your Arduino IDE you can use the Library Manager (available from IDE version 1.6.2). Open the IDE and click to the 'Sketch' menu and then 'Include Library > Manage Libraries'. The Library Manager will open and you will find a list of libraries that are already installed, as well as those that might be ready for installation. You can simply scroll down the list to find the library that you need. Since more than one version of a particular library might be available it is generally wise to install the latest version. Having located the appropriate library, you just need to click on install and wait for the IDE to install the new library. Depending on the speed of your Internet connection, downloading might take a few minutes, but when the installation is complete you should notice an 'Installed' tag (see Fig.3.5). After closing the Library Manager, the new library should be listed in the 'Include Library' menu.

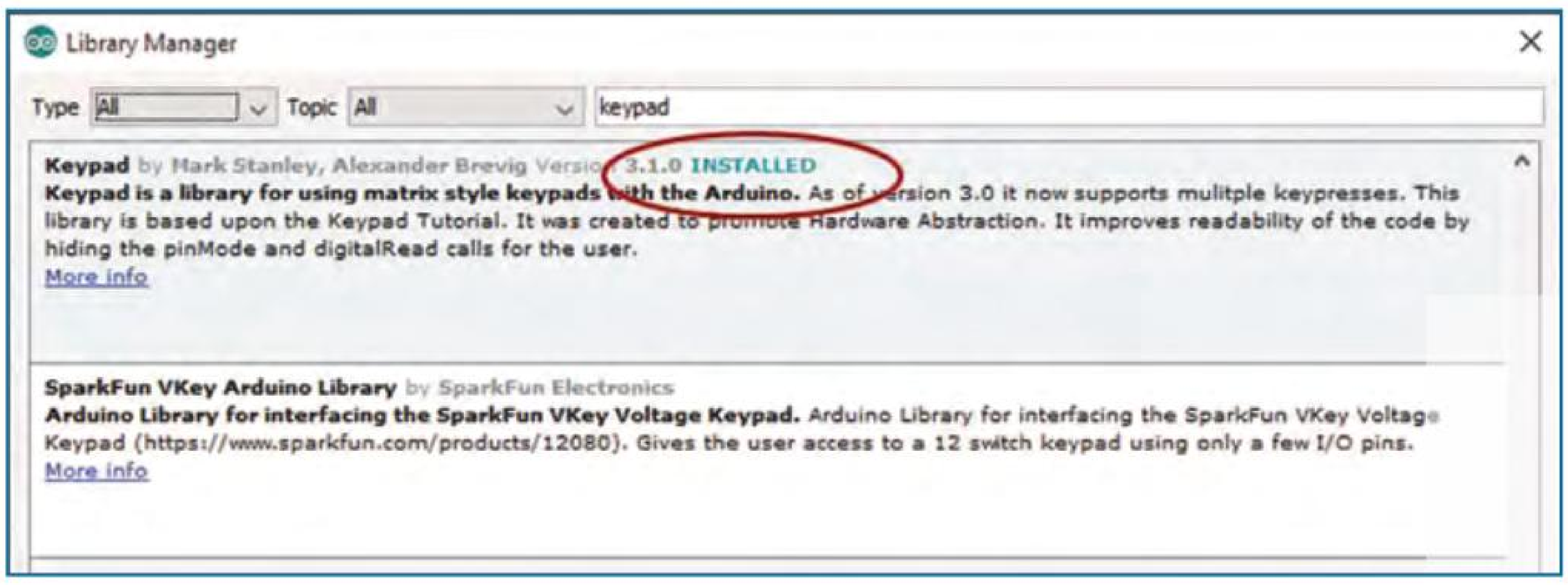
Importing a zipped library

Some libraries are distributed as compressed archives (ie, ZIP files). The compressed folder will have the same name as the library file but will have a different file extension (ie, **.zip**). The compressed archive will invariably comprise several files that have all been zipped into the archive. For example, a **.cpp** file, a **.h** file, a **keywords.txt** file, and a folder with examples. There's no need to unzip or extract the contents of the archive, as the IDE can do this for you. Simply click on 'Sketch' and 'Include Library'. Then, at the top of the drop down list, select the option to 'Add .ZIP Library'. Next, navigate to the location of the **.zip** file (for example, in your 'Downloads' folder) and click to open it. If you now return to the 'Sketch' and 'Import Library' menu you should now see the library at the bottom of the drop-down menu. The zip file will have been uncompressed in the libraries folder, ready for you to use in your own code. Note that, although the library will be ready for use within your code, the examples for the library in question will not be added to the 'Examples' sub-menu of the 'Files' menu until after the IDE has restarted. Finally, it is also possible to install a library manually (ie, without using the IDE to perform the task) and information on how to do this can be found at: **https://www.arduino.cc/en/Guide/Libraries**

Using the keypad library

The keypad library provides you with some useful functions that you can use in your code. This library is available via the Arduino Library Manager; to install it you simply use the menu 'Sketch > Include Library > Manage Libraries' as described earlier. If you search for 'Keypad' you should be able to click on its entry and the 'Install' button will appear. Note that the keypad library configures the Arduino's internal digital I/O pull-up resistors so you won't need external resistors or diodes. The keypad library also ensures that all unused column pins are high-impedance.

Listing 3.2 shows an example of using some of the keypad library functions to read the keypad and then display the returned characters using the IDE's Serial Monitor (if you want to test this code don't forget to select 'Tools' and then 'Serial Monitor' first).



keypad

Keypad by Mark Stanley, Alexander Brevig Version 3.1.0 INSTALLED
Keypad is a library for using matrix style keypads with the Arduino. As of version 3.0 it now supports mulitple keypresses. This library is based upon the Keypad Tutorial. It was created to promote Hardware Abstraction. It improves readability of the code by hiding the pinMode and digitalRead calls for the user.
More info

SparkFun VKey Arduino Library by SparkFun Electronics
Arduino Library for interfacing the SparkFun VKey Voltage Keypad. Arduino Library for interfacing the SparkFun VKey Voltage Keypad (https://www.sparkfun.com/products/12080). Gives the user access to a 12 switch keypad using only a few I/O pins.
More info

Fig.3.5. Using the Arduino's Library Manager

Listing 3.2: Keypad example code

```
/* Keypad example code */

#include <Keypad.h>   // Include the keypad library

const byte ROWS = 4;  // The keypad has four rows
const byte COLS = 4;  // and four columns
char keys[ROWS][COLS] = {
  {'1','2','3','A'},
  {'4','5','6','B'},
  {'7','8','9','C'},
  {'*','0','#','D'},
};   // Use an array to hold the key values

byte rowPins[ROWS] = {9,8,7,6}; // Define Uno's I/O pin numbers
byte colPins[COLS] = {5,4,3,2};

Keypad keypad =
Keypad(makeKeymap(keys), rowPins, colPins, ROWS, COLS);

void setup() {
Serial.begin(9600);  // Initialize the Serial Monitor
}

void loop() {
char key = keypad.getKey();  // Let's check the keypad ..
if (key != NO_KEY){
  Serial.println(key);        // If we have a key print it!
  }
}
```

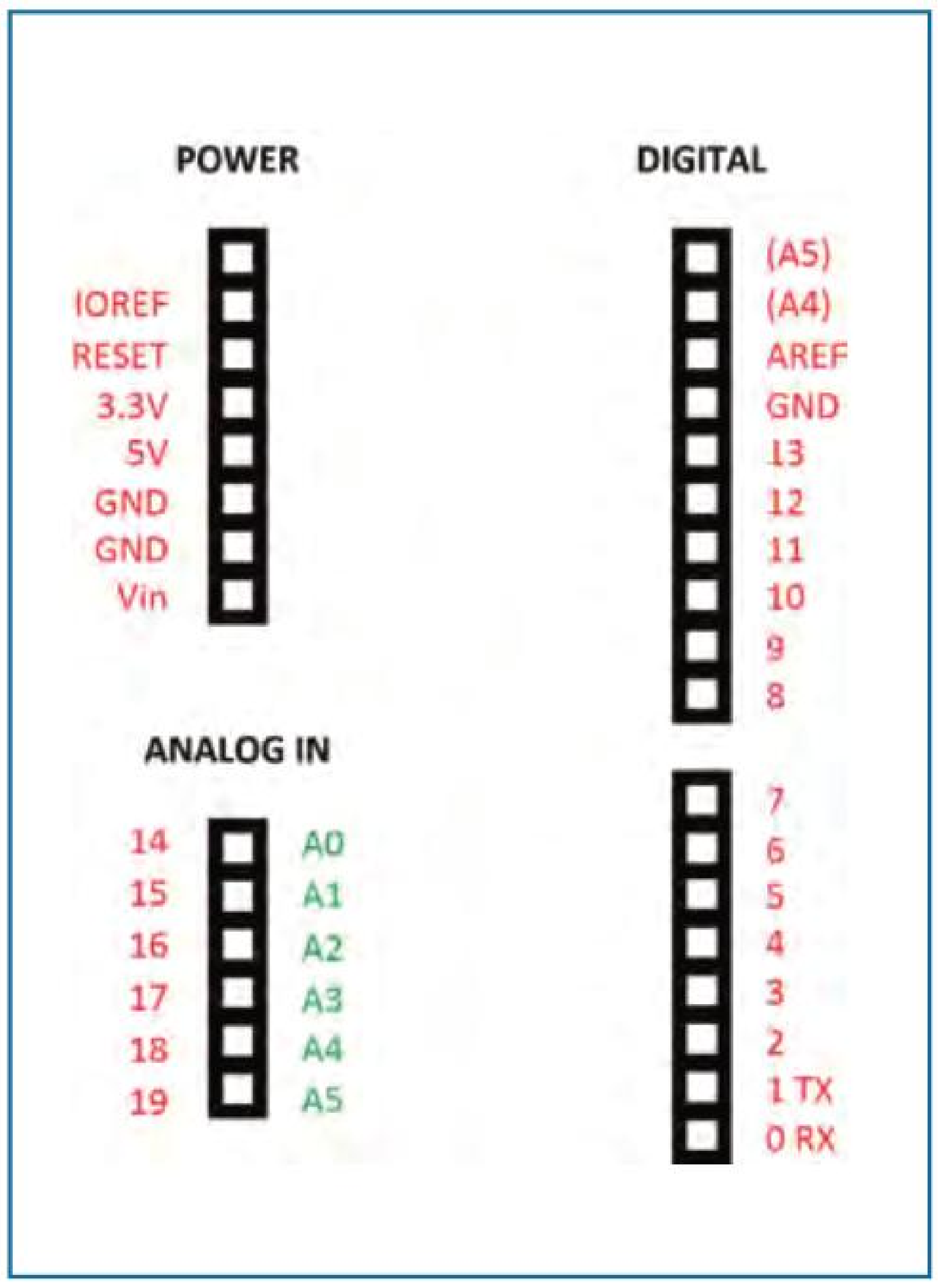


Fig.3.6. The Arduino Uno's I/O pin connections

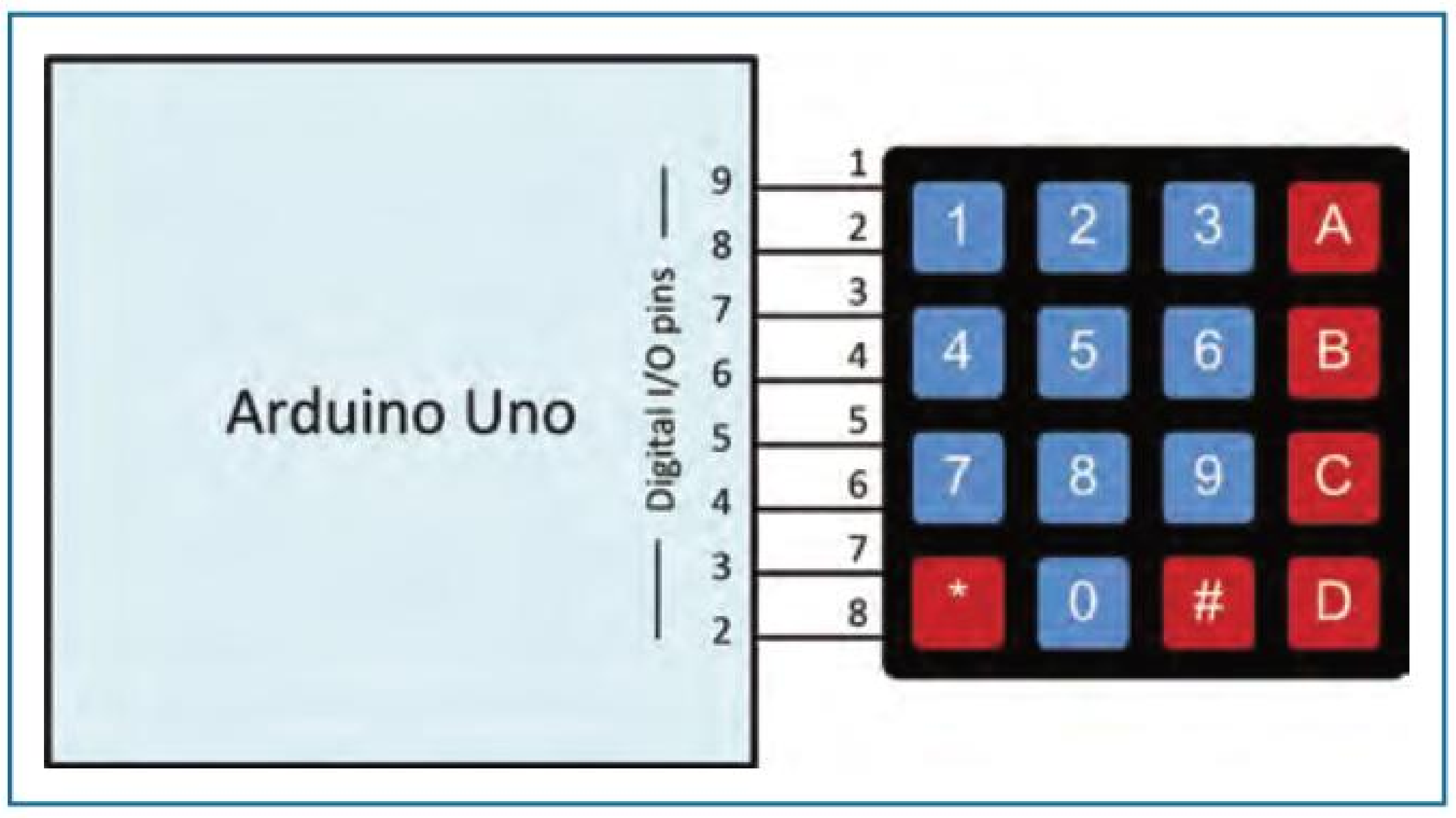


Fig.3.7. Example of interfacing a 4 × 4 matrix keypad to an Arduino Uno

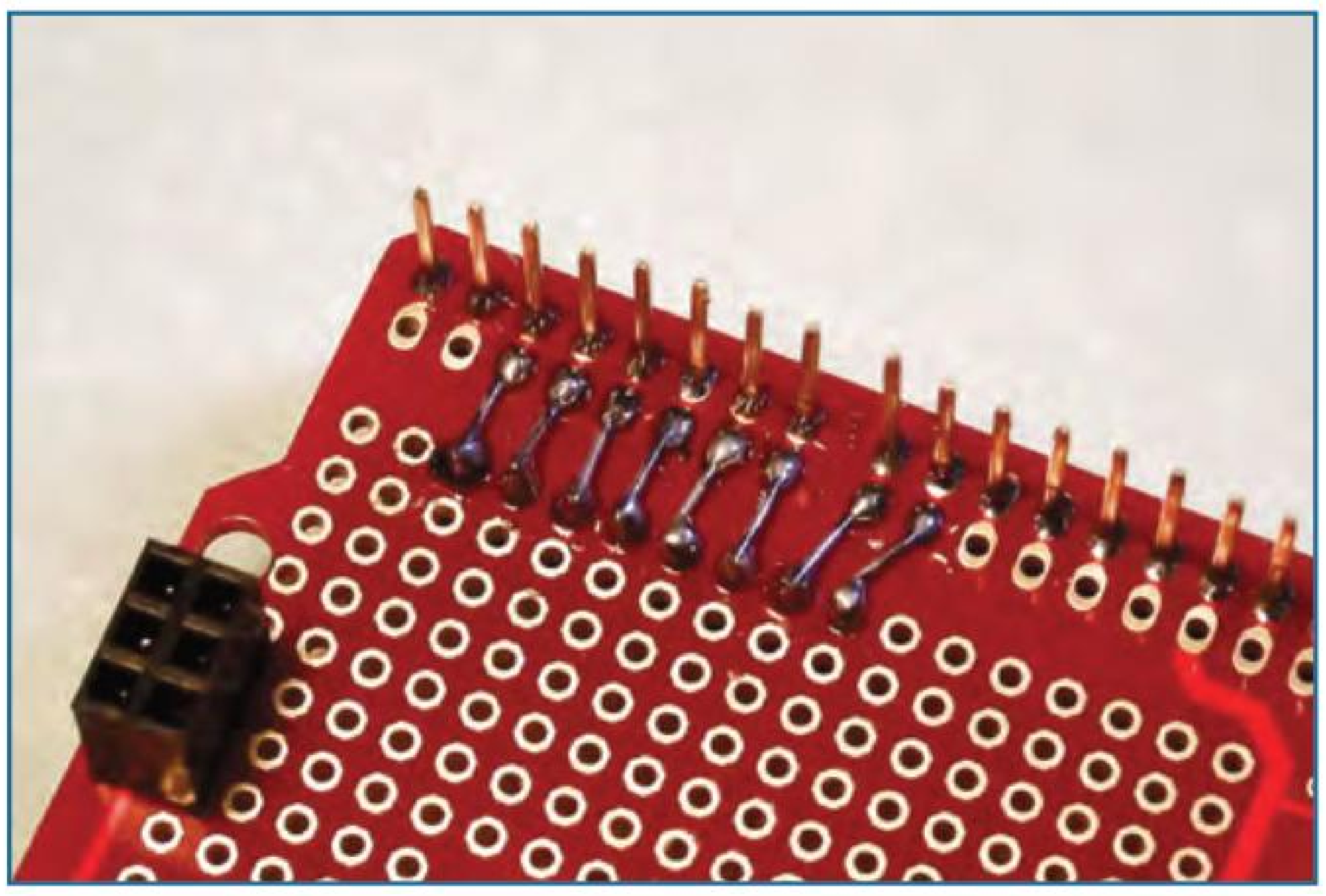


Fig.3.8. Links made under a Prototype Shield. These link digital I/O pins 2 to 9 to the 8-pin male header used to connect the 4 × 4 matrix keypad

Interfacing to an Arduino

For Listing 3.2 the matrix keypad should be connected to digital I/O pins 2 to 9 (see Fig.3.6). Pins 1 to 8 on the keypad are connected to pins 9 to 2 respectively on the digital I/O connector, see Fig.3.7. The problem of connecting the keypad ribbon cable to the Arduino can be easily solved using an Arduino Prototype Shield. This can be fitted with an 8-pin male connector with links to connect to the appropriate digital I/O pins, as shown in Fig.3.8. The Prototype Shield will fit neatly over the Arduino Uno and will have plenty of space available for constructing further I/O circuitry, as we will show later in *Get Real*.

Arduino Workshop: Interfacing LCD displays

In many practical Arduino applications there's a need to be able to display short text messages, for example, temperature, humidity, elapsed time, or the number of events counted. For these, and many other applications, a small LCD panel is all that you need.

Low-cost LCD displays for the Arduino have a built-in controller and drivers and they generally provide either two or four rows of 16 characters with each character comprising a matrix of five by eight dots. In order to provide an acceptable display in low-ambient light an LED backlight is usually incorporated. Fig.3.9 shows a low-cost LCD display shield based on the popular 1602 LCD display.

Interfacing to an Arduino

The simplified block schematic of a typical LCD display module is shown in Fig.3.10. The module requires eight data bus connections, together with enable and register select control signals. The LED backlight requires two further connections marked A and K. In a later installment we will show how we can use the I^{2}C bus to simplify connection to an Arduino using only four instead of 12 wires. The pin connections for a standard 1602 LCD display are listed in Table 3.1 and shown in Fig.3.10.

Configuring an LCD display

In order to configure an LCD display for use with an Arduino, the `LiquidCrystal()` function must first be used to specify the type of display and the I/O pins that will be used with it. The syntax for the function involves a list of several parameters (these are enclosed in brackets):

```
LiquidCrystal(rs, rw, enable,
d0, d1, d2, d3, d4, d5, d6, d7)
```

The parameters are as follows:

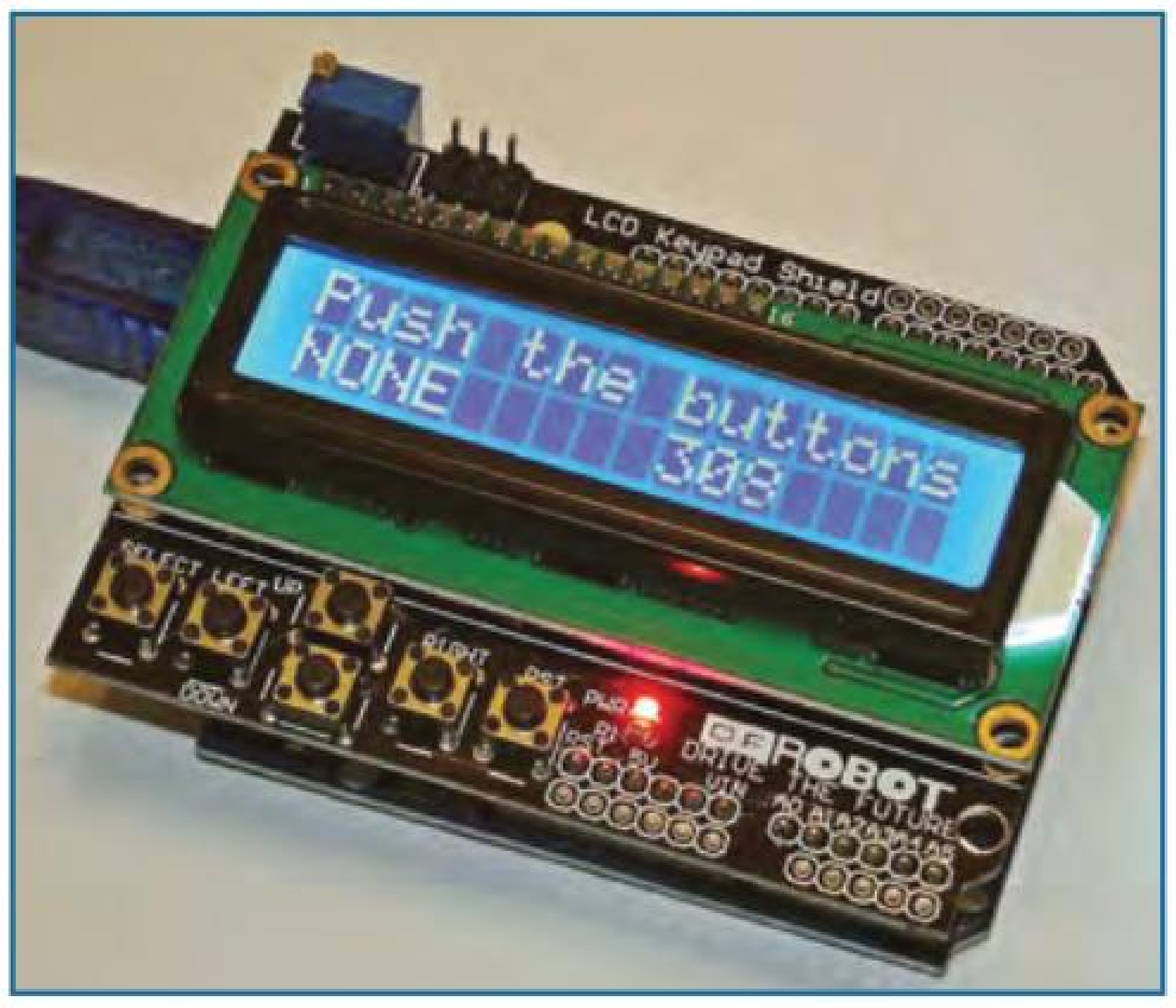


Fig.3.9. A low-cost LCD Shield for the Arduino Uno. This particular shield also provides five buttons that can be used for input as well as a reset button

`rs` – number of Arduino pin connected to RS pin on the LCD
`rw` – number of Arduino pin connected to RW pin on the LCD (optional)
`enable` – number of the Arduino pin connected to the enable pin on the LCD
`d0, d1, d2, d3, d4, d5, d6, d7` – numbers of Arduino pins connected to corresponding data pins on the LCD.

Usefully, the display can be controlled using just four of the eight data lines. With only four data lines the pin numbers for D0 to D3 can be omitted and the lines left unconnected. Furthermore, since we are only interested in writing data to the module and not reading from it, the Read/Write signal can be hard-wired to 0V and this parameter can also be omitted from the list of function parameters. Thus the most basic syntax is:

```
LiquidCrystal(rs, enable, d4, d5, d6, d7)
```

Listing 3.3 shows a simple example of using some of the LCD library functions to set up a 16 character two-line display and send some text and data to it. If you want to test this routine you will need to connect a 1602 display using the digital I/O pins shown in Fig.3.12.

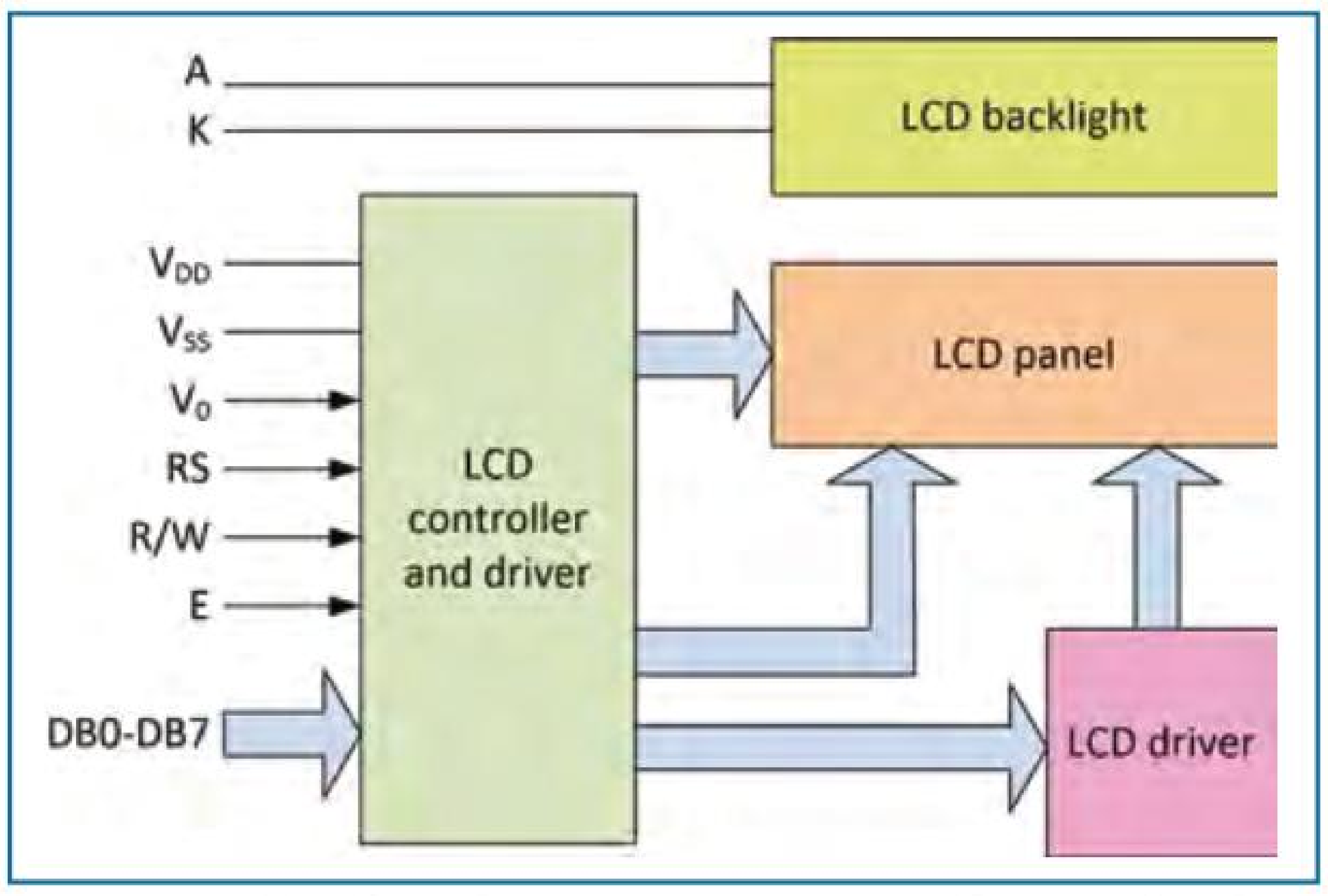


Fig.3.10. block schematic of a typical LCD display module suitable for use with an Arduino

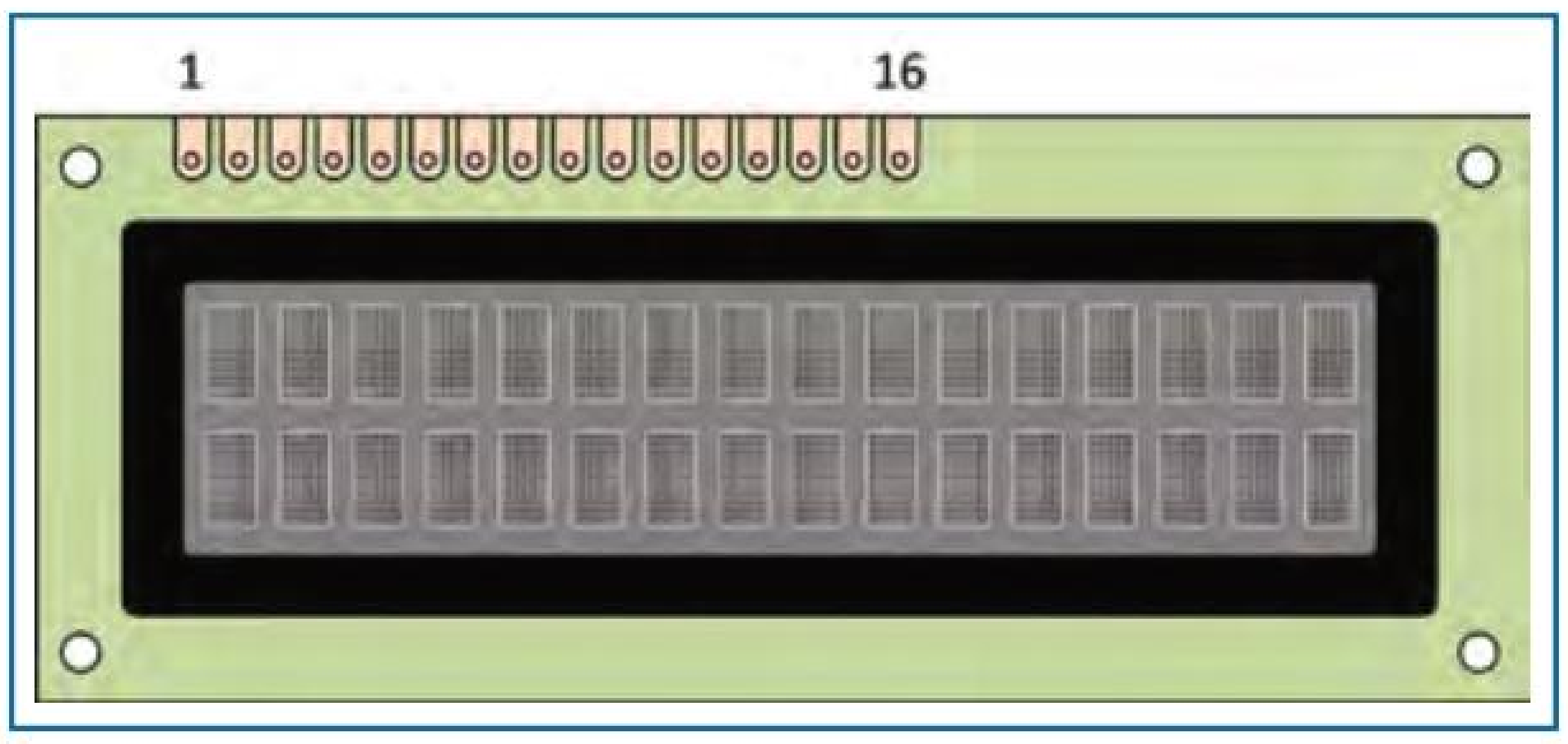


Fig.3.11. 1602 LCD display pin connections

Get Real : A simple access control system system

In last month's *Get Real* we described a very simple security system. This month, and continuing with the security theme, we are going to show how the Arduino Uno can be used together with a low-cost keypad and LCD display to provide a simple but highly effective entry/access control system. This system could be used for operating a door release solenoid or perhaps in conjunction with the alarm system that we described last month.

You will need:

Arduino Uno with power supply
USB Type-A to Type-B cable
Computer with an available powered USB port
1 16 × 2 LCD 1602-type display
1 16-key matrix keypad (see text)
1 Arduino Uno prototype shield (see text)
1 piezoelectric sounder (must be a DC-operated type), PZ1
1 5V miniature PCB mounting relay (see text), RL1
1 BC548 NPN transistor, TR1
1 10kΩ miniature skeleton pre-set potentiometer, RV1
1 330Ω 0.25W resistor, R1
1 220Ω 0.25W resistor, R2
1 1kΩ 0.25W resistor, R3
1 1N4148 diode, D3
1 miniature LED, D4
1 three-way terminal block, SK1
1 SPST switch , S1
1 9V battery (see text), B1

Listing 3.3: LCD example code

```
//* LCD display example code */

#include <LiquidCrystal.h>    // Include the LCD library
LiquidCrystal lcd(7, 6, 5, 4, 3, 2);  // I/O pin numbers for LCD

void setup() {
  // set up the LCD's number of columns and rows:
  lcd.begin(16, 2);    // Display has 16 columns and 2 rows
  lcd.print("LCD Display Test");   // Display a message
}

void loop() {
  lcd.setCursor(0, 1); // Begin on the second line
  lcd.print(millis() / 1000);   // Display seconds
}
```

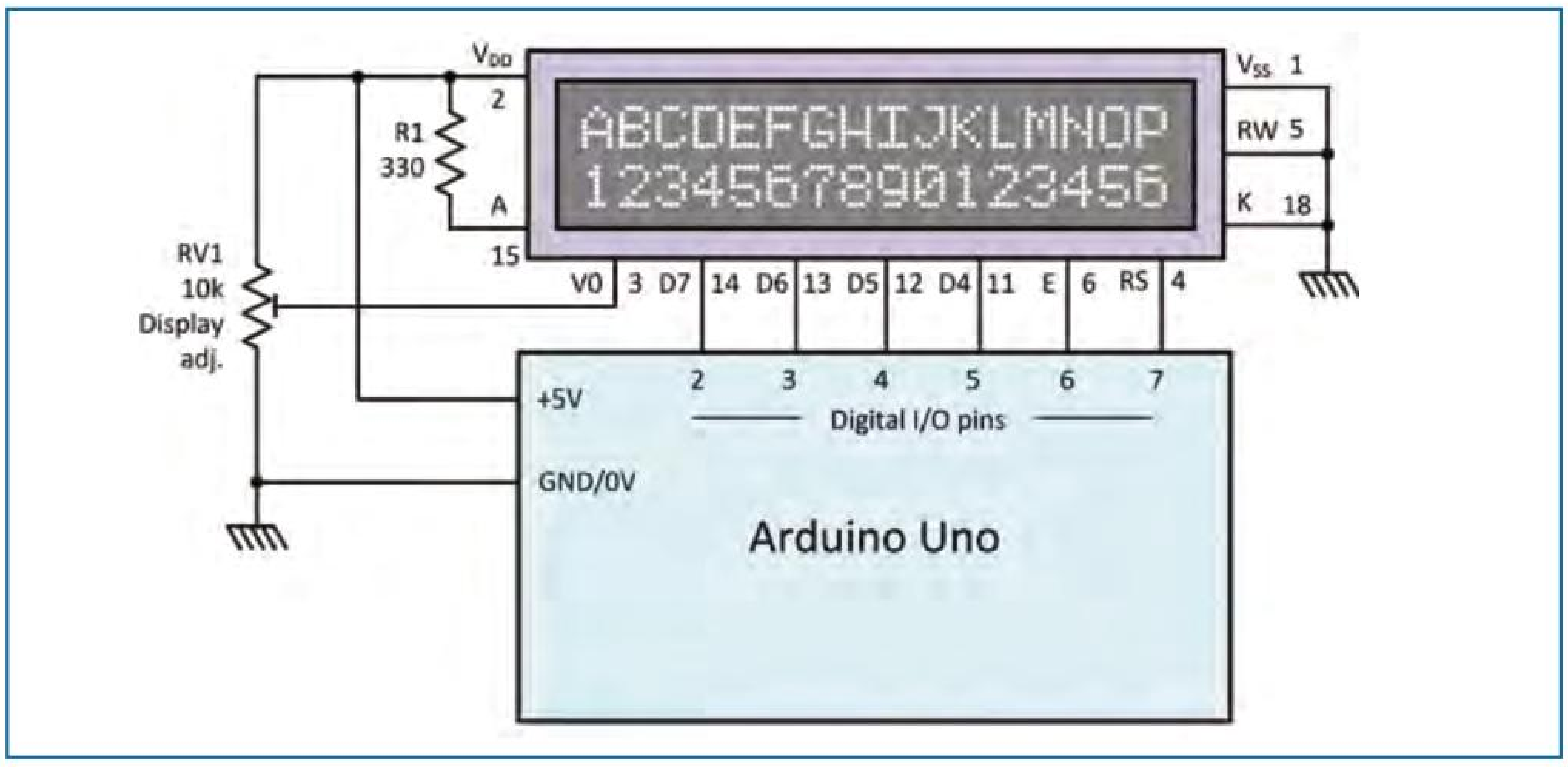


Fig.3.12. Interfacing a 16 × 2 LCD display to an Arduino Uno

Pin number	Designation	Function
1	VSS	Ground/0V
2	VDD	+5V
3	V0	Display contrast adjustment
4	RS	Register select
5	R/W	Read/write
6	E	Enable
7	D0	Data bus 0
8	D1	Data bus 1
9	D2	Data bus 2
10	D3	Data bus 3
11	D4	Data bus 4
12	D5	Data bus 5
13	D6	Data bus 6
14	D7	Data bus 7
15	A	+4.2V LED backlight supply
16	K	0V LED backlight supply

Table 3.1: pin connections for a standard 1602 LCD display

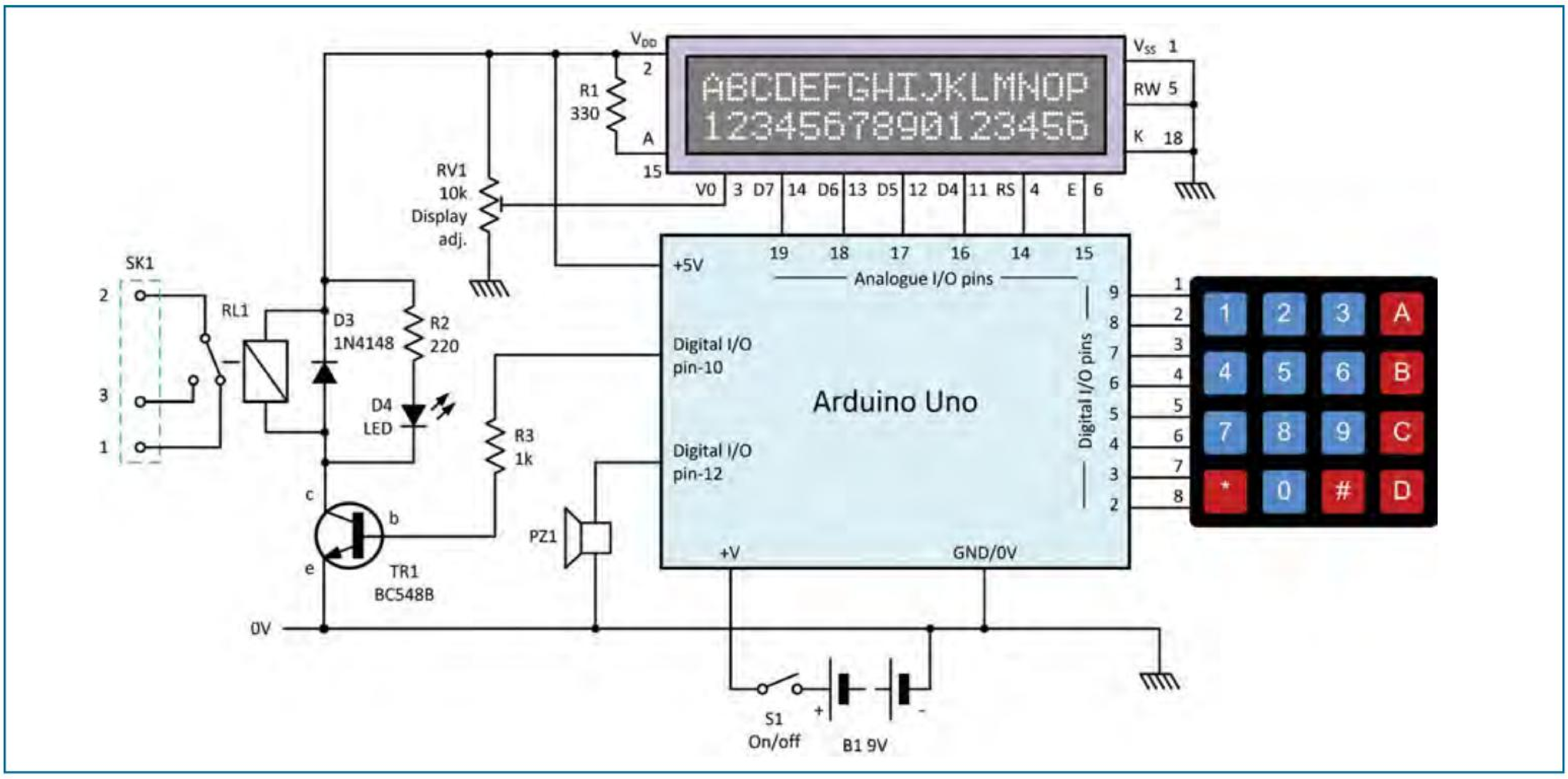


Fig.3.13. Complete circuit of the simple Arduino-Uno-based access control system

Circuit

The complete circuit of our simple Arduino Uno-based access control system is shown in Fig.3.13. The circuit uses low-cost commonly available components. The 16 × 2 LCD display and 16-key keypad are widely available from a number of suppliers including those based in the Far East. The miniature PCB relay should be a 5V type and should have suitably rated contacts. The component used in the prototype was rated at 10A 250V AC and this should cope with most door release actuators systems. A three-way terminal block, SK1, provides connection to the door actuator.

In use, the user enters a passcode consisting of a string of alphanumeric characters followed by the '#' key. A beep from the piezoelectric sounder provides confirmation that the user has entered a character on the keypad. When the correct passcode has been entered the LED will become illuminated and the relay will operate for a time that can be preset within the code. The correct passcode is also preset in the code.

Using the prototype shield

The prototype shield mounts directly over the Arduino Uno. It provides a convenient, low-cost way of assembling the components and making connections to the Uno's I/O and power headers.

Code

Listing 3.4 shows the complete code for the simple Arduino-based access control system. Once again, to help you understand what's going on we've included numerous comments in the code. Note that, in order to interface both the matrix keypad and LCD display (requiring a total of 14 digital output lines) we've used the Uno's six analogue inputs to provide six additional digital outputs. To be able to do this, we just need to refer to the extra data lines as pins14 to 19 (see Fig.3.6). Hence, the LCD's RS line will be connected to digital pin 14 (marked as A0 on the Uno), the E line will be driven by digital pin 15 (marked as A1 on the Uno), and so on.

The code requires three libraries; `LiquidCrystal.h`, `keypad.h` and `Password.h`. The first two of these provide functions that facilitate the use of the LCD display and the matrix keypad, while the third deals with setting and checking the passcode string. You could, of course, develop some of your own code to do this but there's little point in spending time on a task that someone else has provided a simple and elegant solution to, and has been willing to share that solution with the rest of the community.

The code should be entered into the IDE and then saved before compiling and uploading it to the Uno, as described in last month's *Arduino Workshop*. Don't forget to save your work by clicking on 'File' and 'Save' or 'Save As…' when you finish. Next click on 'Sketch' and 'Verify/Compile'. You will, of course, need to add the library files to your IDE, as described earlier in this *Teach-In*.

Testing

When you've corrected any coding errors that the compiler reports you will be ready to upload your code to the Uno. Just click on the upload arrow and watch the progress report. When the Uno performs a reset you will see some characters appearing across the LCD for a short time, after which the display will clear and

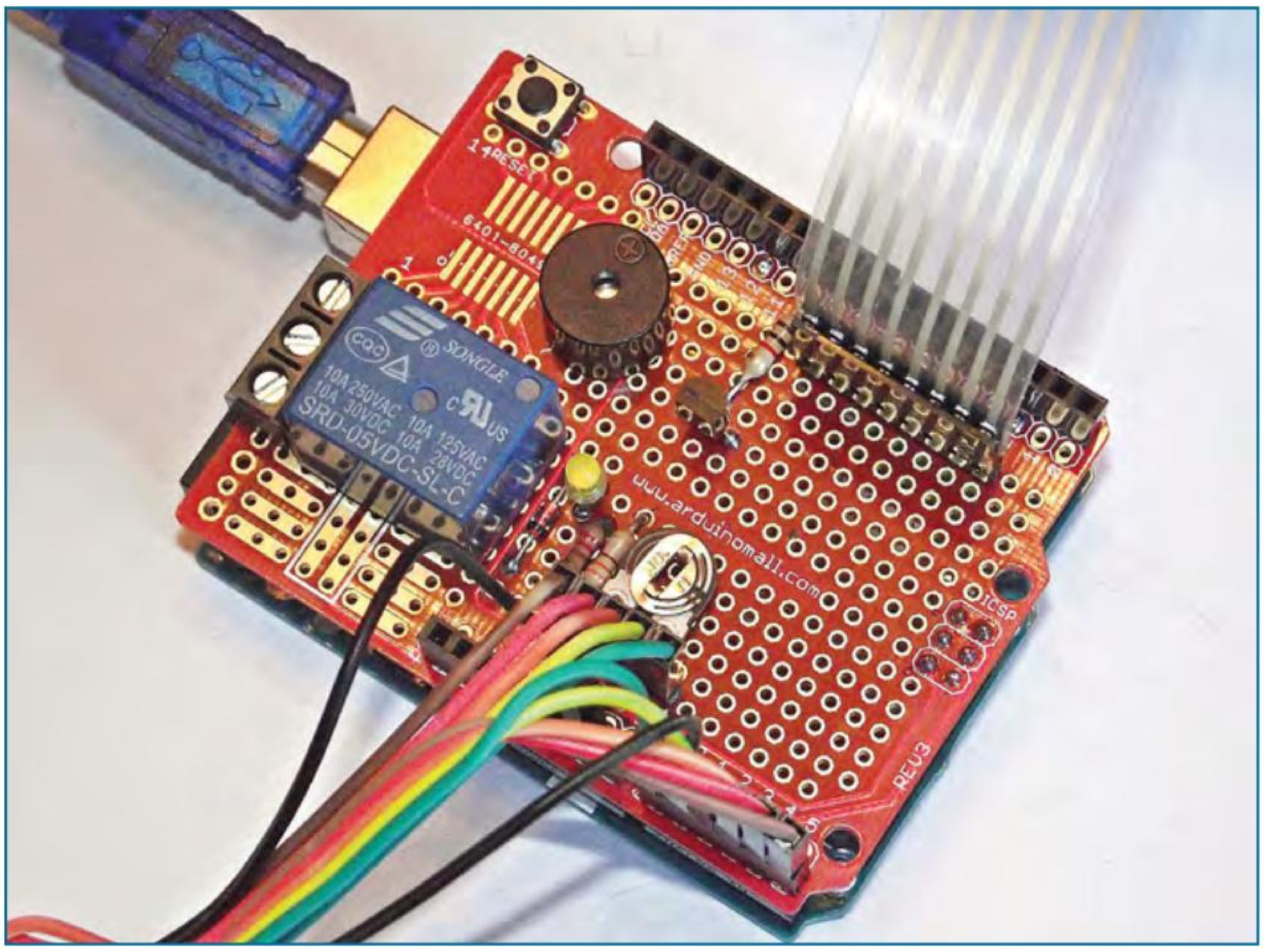


Fig.3.14. The Prototype Shield provides connections for the LCD display and keypad and is mounted above the Arduino Uno

Listing 3.4: Code for the simple Arduino-based access control system

```
/* Arduino access control system */

// Include the library code:
#include <LiquidCrystal.h>
#include <Keypad.h>
#include <Password.h>

// Initialize the LCD with the numbers of the interface pins
LiquidCrystal lcd(14, 15, 16, 17, 18, 19);

const byte ROWS = 4;
const byte COLS = 4;
char keys[ROWS][COLS] = {
  {'1','2','3','A'},
  {'4','5','6','B'},
  {'7','8','9','C'},
  {'*','0','#','D'},
};

byte rowPins[ROWS] = {9,8,7,6};
byte colPins[COLS] = {5,4,3,2};

int outPiezo = 12;
int outRelay = 10;

Keypad keypad = Keypad(makeKeymap(keys), rowPins, colPins,
ROWS, COLS);

Password password = Password( "ABCD" ); // Change as required

void setup(){
  pinMode(outPiezo, OUTPUT);
  pinMode(outRelay, OUTPUT);
  // Set up the number of columns and rows on the LCD display
  lcd.begin(16, 2);
  // Print a message to the LCD.
  lcd.print("Enter Passcode"); // User prompt to display
  keypad.addEventListener(keypadEvent);
  keypad.setDebounceTime(250);
}

void loop(){
  keypad.getKey();
}

void keypadEvent(KeypadEvent eKey){
  switch (keypad.getState()){
    case PRESSED:
      lcd.setCursor(0, 1);
      lcd.print("*");
      digitalWrite(outPiezo, HIGH); // Beep to confirm keypress
      delay(50);
      digitalWrite(outPiezo, LOW);
      delay(50);
      lcd.setCursor(0, 1);
      lcd.print(" ");
      switch (eKey){
       case '#': checkPasscode(); break; // If # was it
correct?
        default:
           password.append(eKey);
      }
   }
```

display the message, 'Enter Passcode'.

At this point the Uno is waiting for user input. If you then press a key, you will hear a beep, which informs you that the character that you've pressed has been accepted. If you press several further characters in succession followed by a '#' the entered passcode will be checked and a message, either 'Welcome' or 'Invalid Passcode' will appear. If the correct passcode (ABCD) has been entered prior to the '#' key the LED should become illuminated and the relay should operate for one second (sufficient to release the door). This time interval can easily be changed by modifying the value shown in the code.

Finally, the access control system requires a reliable 9V DC supply. This could take the form of a suitably rated mains supply (9V at 500mA minimum) or a float-charged battery with an output of between 8V and 12V.

Going further

As usual, there's a great deal of scope for going further with our simple Arduino-based access control system. The most obvious enhancement would be the addition of access codes that would enable different levels of access (ie, open some doors but not others). A lock-out feature could be incorporated to prevent multiple attempts at code entry. This could enforce an obligatory time delay after, say, the third or fourth attempt at entering a code. Alternatively, the system could be placed in a 'lock down' mode, triggering an alarm or sending a message to a remote supervisory system.

An important note for Mac users

Finally, thanks to reader Michelle O'Brien we've become aware that due to technical changes introduced by Apple in the interest of increased security, some (particularly non-genuine) Arduino USB interfaces will not work on Macs running OS X El Capitan. This problem seems to arise from the fact that due to enhanced system integrity protection, the latest Mac OS no longer supports unsigned serial drivers. This could potentially be a problem with a large variety of legacy hardware that relies on USB drivers from different manufacturers.

The situation should be less of a problem with the drivers that provide connectivity with genuine Arduino boards, but some users have reported difficulties with genuine boards that have used the (previously fully functional) FTDI drivers. If you experience difficulties it is worth taking a look at the Arduino Forum, **https://forum.arduino.cc/index.php**. We also suggest that you should be very careful if attempting to use one of the unapproved 'fixes' being recommended on several websites. These could be dangerous as they could adversely affect the stability and security of your computer system. So, if you do go ahead with a 'fix', it's essential to take a full back-up before making a start.

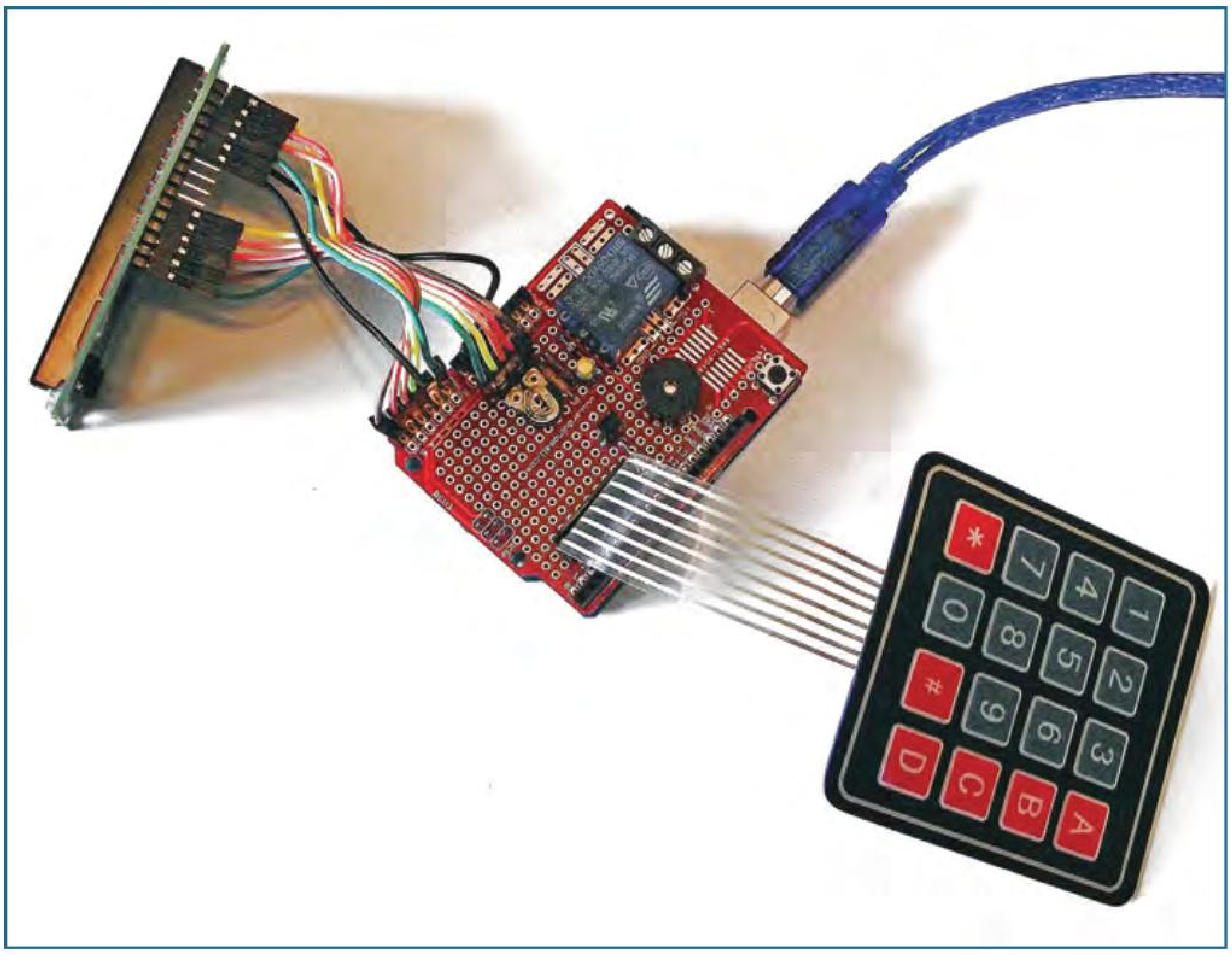


Fig.3.15. The complete Arduino Uno access control system showing the backlit 16 × 2 LCD on the left and the 4 × 4 matrix keypad on the right. The blue lead at the top is the USB programming connection to the PC

Next month

In next month's *Teach-In 2016 Exploring the Arduino* we will be looking at ways in which the Arduino can sense and act upon what's going on in the real world. To this end, *Arduino Workshop* looks at the Arduino's analogue ports, while *Arduino World* introduces some low-cost devices that can sense temperature. Our programming feature, *Coding Quickstart*, explains the functions that will let you use serial communication via the Arduino's USB port. Finally, *Get Real* will show you how you can build a simple thermostatic controller based on the Arduino Uno.

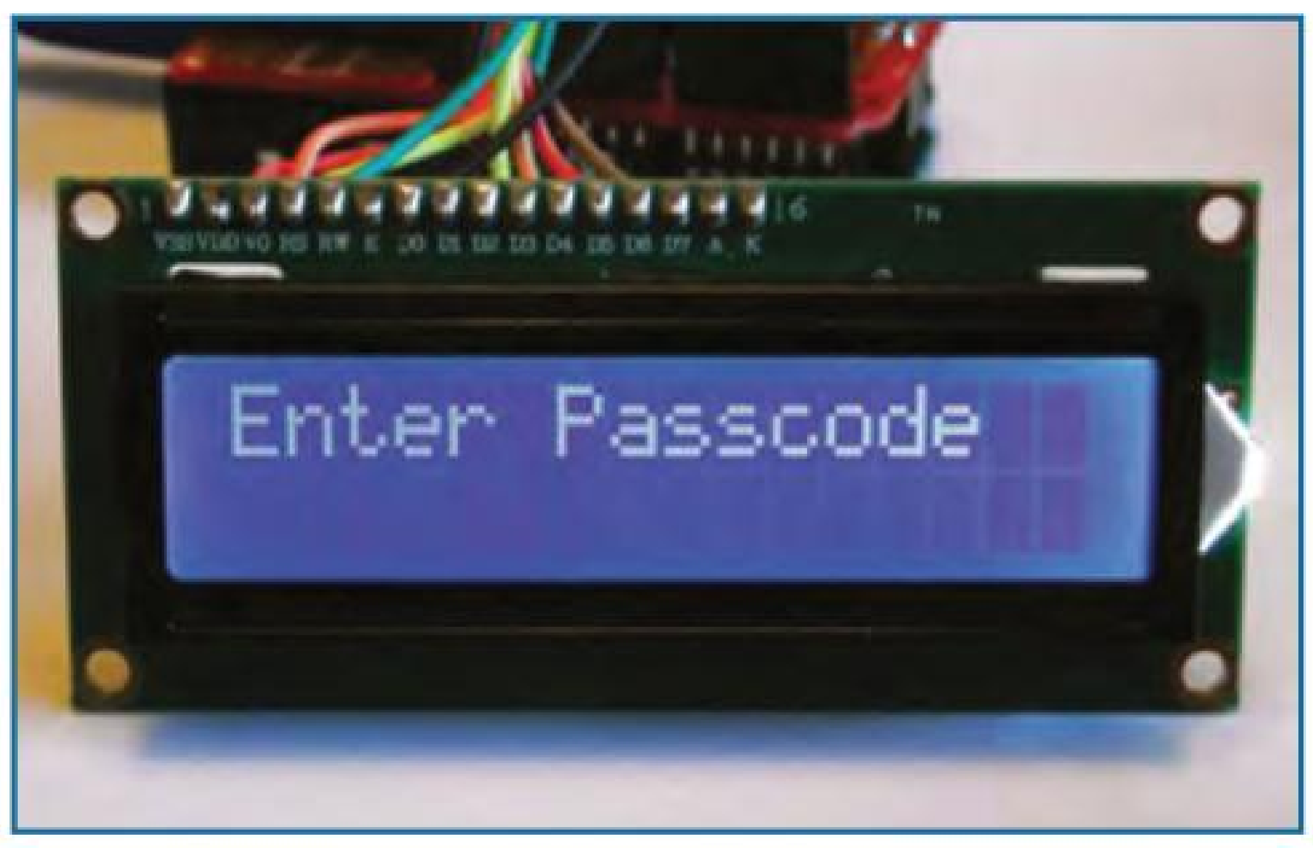


Fig.3.16. 'Enter Passcode' – prompts users to enter a code to provide access when the relay operates

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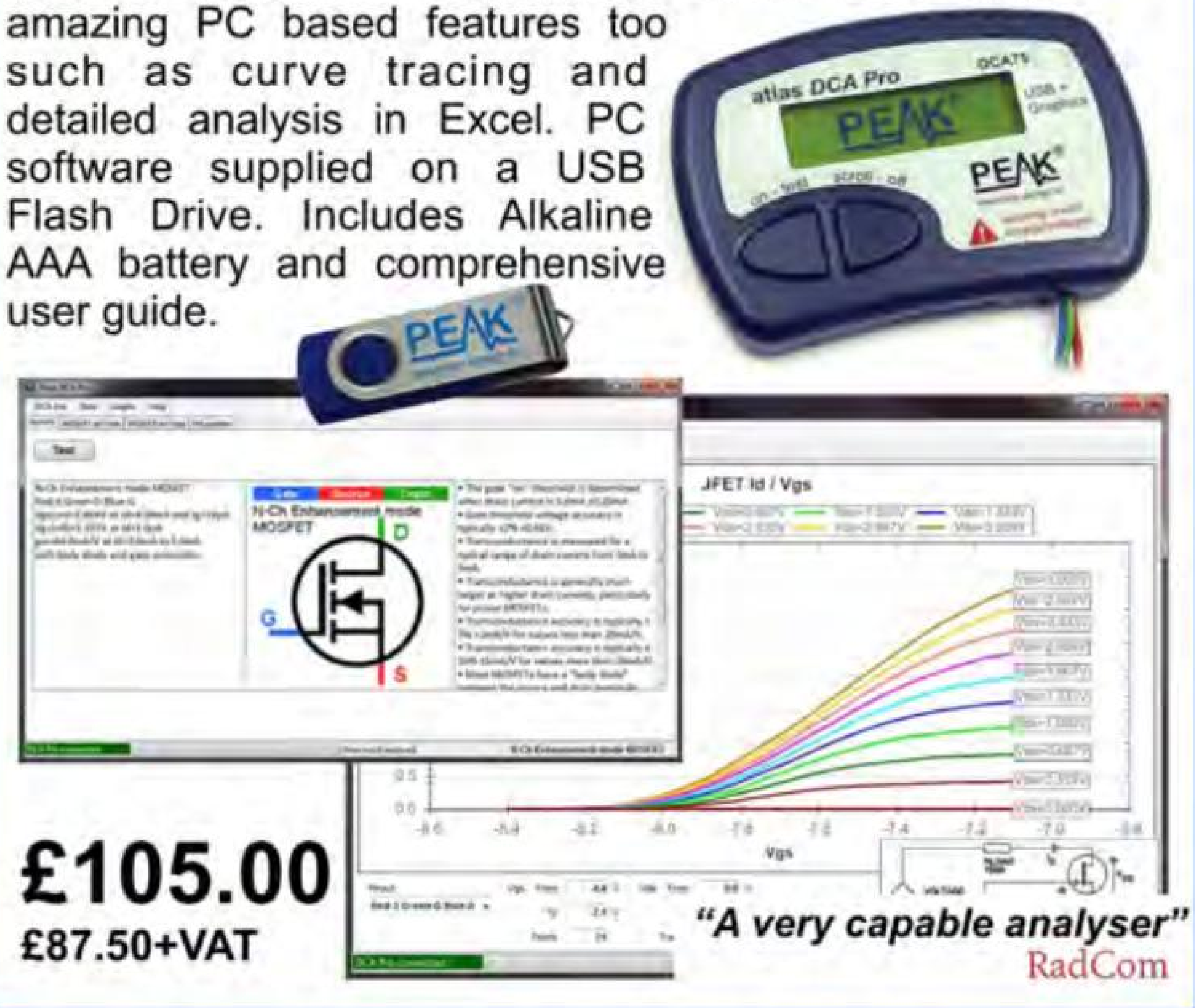
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NET WORK

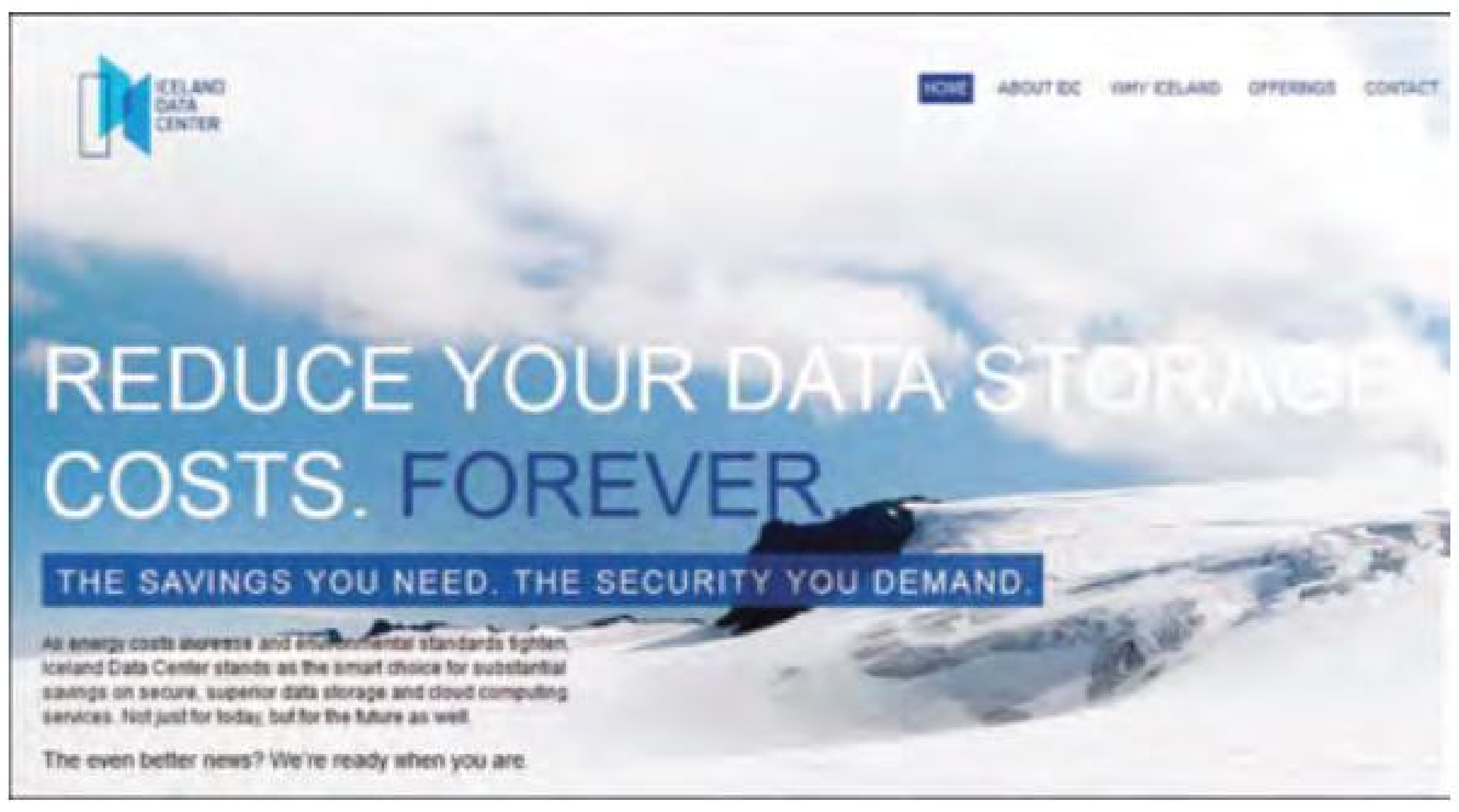
by Alan Winstanley

Chilling out

MANY READERS cannot fail to have noticed how the world of Internet usage and personal computing has undergone a step-change in terms of approach, design and usability and, as I mentioned in the last few months, the web is fast becoming unrecognisable compared with the pioneering offerings of static web design and simple email programs of ten or twenty years ago.

Progress is often a good thing. Cloud computing has rapidly become embedded in many aspects of our lifestyle and an integral part of Internet-of-Things technology itself; online storage is coming out of everyone's ears and even the writer's new PC motherboard included some free cloud storage to help with data archiving or backups. For as many months as I care to remember, I have viewed with great caution the inevitable migration towards cloud-based services. Cloud storage is fine if you have a useful level of bandwidth to make the most of it, but ordinary end-users don't know where files are stored, except that they are 'out there' somewhere, with your data hopefully kept in safe hands. Google has a global fleet of data centres that handles trillions of search queries, Amazon touts AWS (Amazon Web Services) as its own cloud-based platform and Microsoft offers its own cloud service called Azure. Much focus of these vast server warehouses is on energy efficiency, with Google, for example, sharing its knowhow to help drive down their power consumption. In Iceland, a new data storage unit (**www.icelanddatacenter.com**) has been built that relies on the Icelandic (chilly) environment to keep things cool, promising a 20% reduction in cloud computing costs.

The term 'SaaS' – software as a service – describes programs that are hosted on remote servers, as opposed to running desktop software on the end-user's (or client's) PC. Internet users will see this all the time, eg with online banking (noting that, as I write, HSBC's online banking has been fending off a DDoS attack in January). The SaaS model depends on users logging into them over a network, in the same way that commercial dumb terminals – little more than screens and keyboards – have been widely deployed in business for decades. (In the 1980s, the author's business career was dominated by an HP3000 monochrome terminal sitting on his desk. In those pre-email days a major leap forward was made when the telex system was interfaced to it and paperless communication finally arrived!)



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Hutber's Law

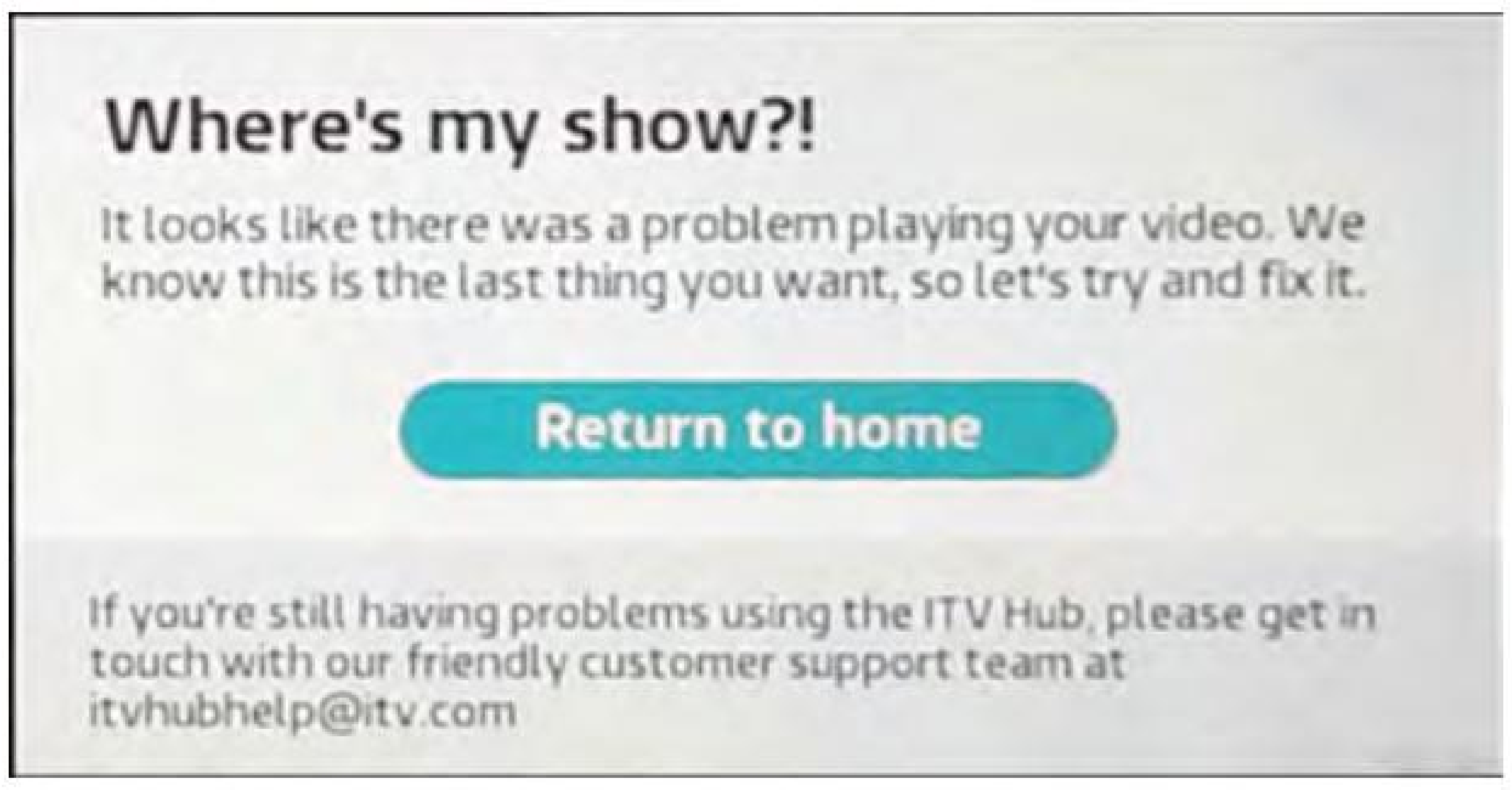
Apart from remote software, we are now bombarded by so-called 'apps', the trendy name for programs optimised for phones and tablets, and some of their design trends have spread to website design and desktop programs too. Designer-itis is spreading like the plague, and bloated websites are behaving more like apps in their own right. Progress can sometimes seem more like a step backwards: Hutber's Law says that 'improvement means deterioration'; ie, supposed new benefits can obscure a change for the worse behind the scenes. A recent example I ran across was Abelssoft's *YouTube Song Downloader*, a handy little Windows program that I use occasionally to unearth old music tracks (**www.abelssoft.de**). Simply enter a search term (song title, band or singer) in the desktop program and it goes off and searches YouTube for any matches. Downloading an MP3 or .avi video (or both, if wanted) onto hard disk is effortless, although the copyright ban-hammer stomps on some downloads. The 2015 version of this program had the classic Windows 7 'look and feel' that made the program simple and intuitive to use. Among other things, attractive and well-designed icons with colour gradients made their purpose clear and buttons were gathered on a simple self-explanatory navigation bar.

Tempted by the program's 'Update Check' button, the new 2016 version was soon installed, and to my dismay the flat and featureless Microsoft 'Metro' styling had wreaked havoc all over Abelssoft's GUI design. I found it a backwards step and Patrick Hutber would beam with pride at this retrograde update. A particular gripe is the hide-and-seek navigation that I found highly annoying: buttons appear out of nowhere and disappear again when mousing around. Handy shortcut buttons to the video and audio folders had also vanished. Now the software crashes altogether on the writer's PC every time it's opened. I soon uninstalled this program and reverted to *YouTube Song Downloader 2015* and sanity was restored. Trial versions for Windows and Mac can be downloaded from Abelssoft if you want to give it a free try.

For those who prefer the style of Windows 7, previous columns have shown how Windows 7 (or 8) users can fight off the Windows 10 Upgrade nagware being touted by Microsoft. Even as recently as mid January when I checked Windows Updates on one of my PCs, there were 38 classed as 'Important' and 7 as 'Optional', the latter including KB3035583, which claims to 'resolve issues in Windows' but is in fact the Windows 10 nagger I highlighted before. This update can safely be ignored unless you want to risk the free upgrade to Windows 10.

If you want a new Windows 7 Professional or Windows 8.1 PC in 2016, then you have until the end of October to buy it before they reach ‘end of sales’, leaving Windows 10 as the *de facto* retail OS – just in time for next Christmas. Details of Microsoft Windows lifecycles are at: **http://windows.microsoft.com/en-us/windows/lifecycle**

The tiresome need for constant upgrades is now a regular feature of ‘smart device’ use, which affects tablets, phones and smart TVs too. Updates do sometimes work as intended though; recently trying to view a streaming movie from Wuaki on a smart TV, I found that every movie was suddenly unplayable and none of the catch-up TV apps worked properly any more either. The TV-based apps were up to date, so it was time to check the Wuaki support web pages. Wuaki stated that the Samsung TV firmware might itself need updating, something I found hard to believe as it had worked fine until now, but I persevered and downloaded the latest version on the TV itself. I rebooted the TV and, just for once, the update worked and the catch-up TV and movie channels sprang back into life.



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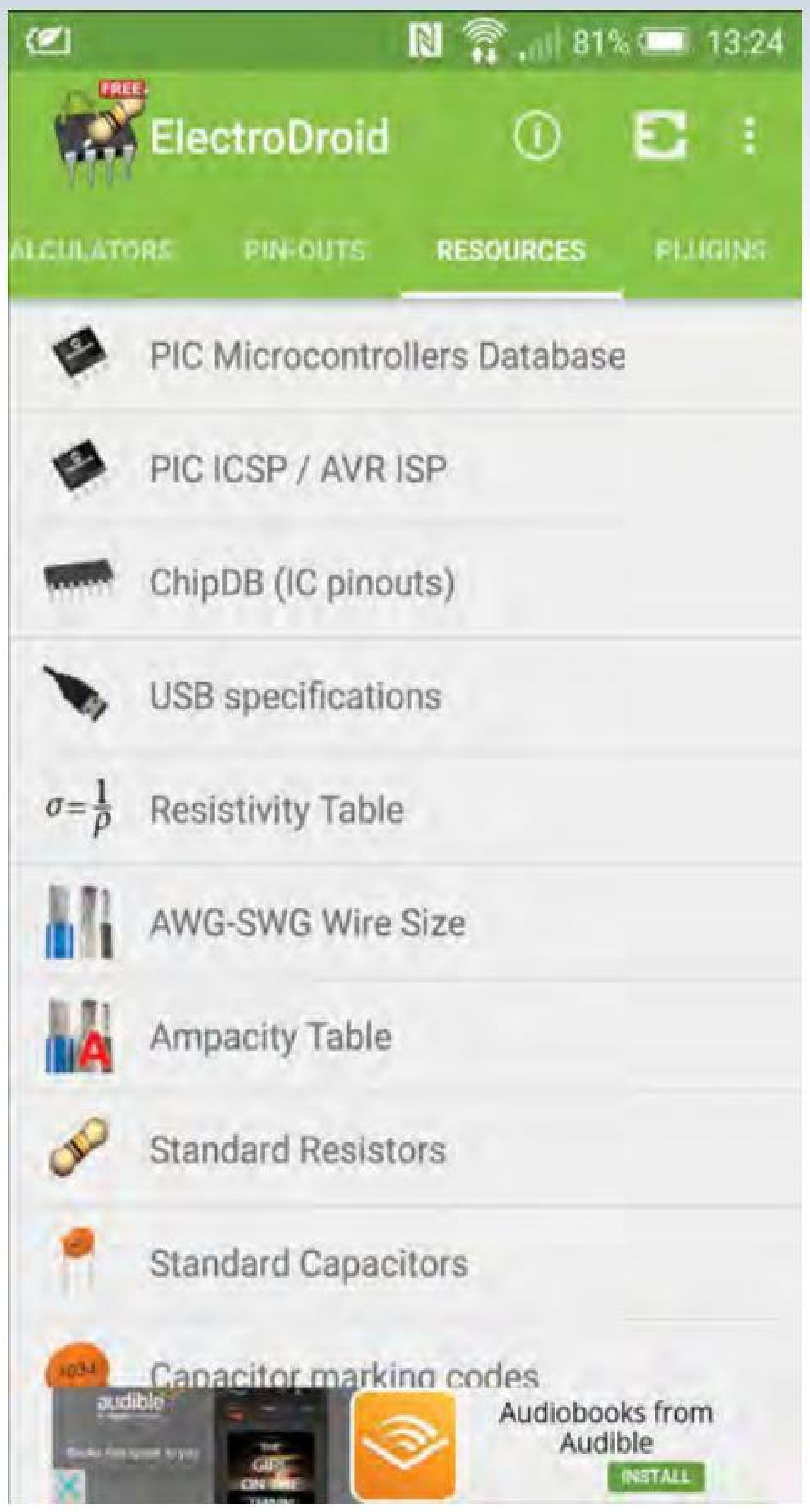
Movie playback error seen on smart TV was cured with a firmware upgrade

Come on down…

Despite their low-cost, many modest apps are genuinely useful and one Android app that electronics hobbyists may enjoy is ElectroDroid. Described by its author as a simple and powerful collection of electronics tools and references, the paid-for version (just £2.38) removes adverts and Version 4.1 supports Android 6.0 (Marshmallow). In fact, ElectroDroid is an exceptional collection of design aids and data that will please any electronics hobbyist or student. Its ‘Calculator’ menu is a cornucopia of colour codes, SMD resistor codes, 555 timer and LM317 regulator values, PCB trace widths, decibels, frequency and far more. That’s just the start, as there are pinouts for many types of audio, digital and video ports, and its Resources area covers wire gauges, SI units, circuit and logic symbols, coin cell dimensions and more besides. ElectroDroid then extends further with a plug-in offering a PICmicro database – don’t expect vast amounts of application data, but pinouts and a summary of specs are there. ElectroDroid can be downloaded from Google Play Store as usual, and expect to have to download updates when Android gets upgraded from time to time.

One of the secrets of being a successful buyer or purchasing manager is to get a good feel for current prices and trends so that you recognise a good bargain when you see one. It would be true to say that the web has empowered consumers like never before, enabling them to shop around online and arm themselves with the best prices, with just a few mouse clicks. For those who shop on Amazon regularly, a good way of tracking prices is to use The Camelizer, one of my favourite power tools for this shopping site. Installing Camelizer is easy and a small ‘camel’ button appears on the browser toolbar. Clicking it when on an Amazon product page produces a graph showing pricing trends for Amazon’s own price and third-party sellers to help you determine whether or not the current ‘price is right’. As a bonus, The Camelizer can email you when a product has reached your preferred target price. Amazon’s Wish List is a good way of tracking items that appeal to you when casually surfing around, but one Amazon service that is firmly disabled in my book is the 1-Click option, to prevent items being purchased accidentally.

The useful Camelizer plug-in can be downloaded from **www.camelcamelcamel.com** and it works fine in Firefox, Chrome and Safari across many of Amazon’s international sites.



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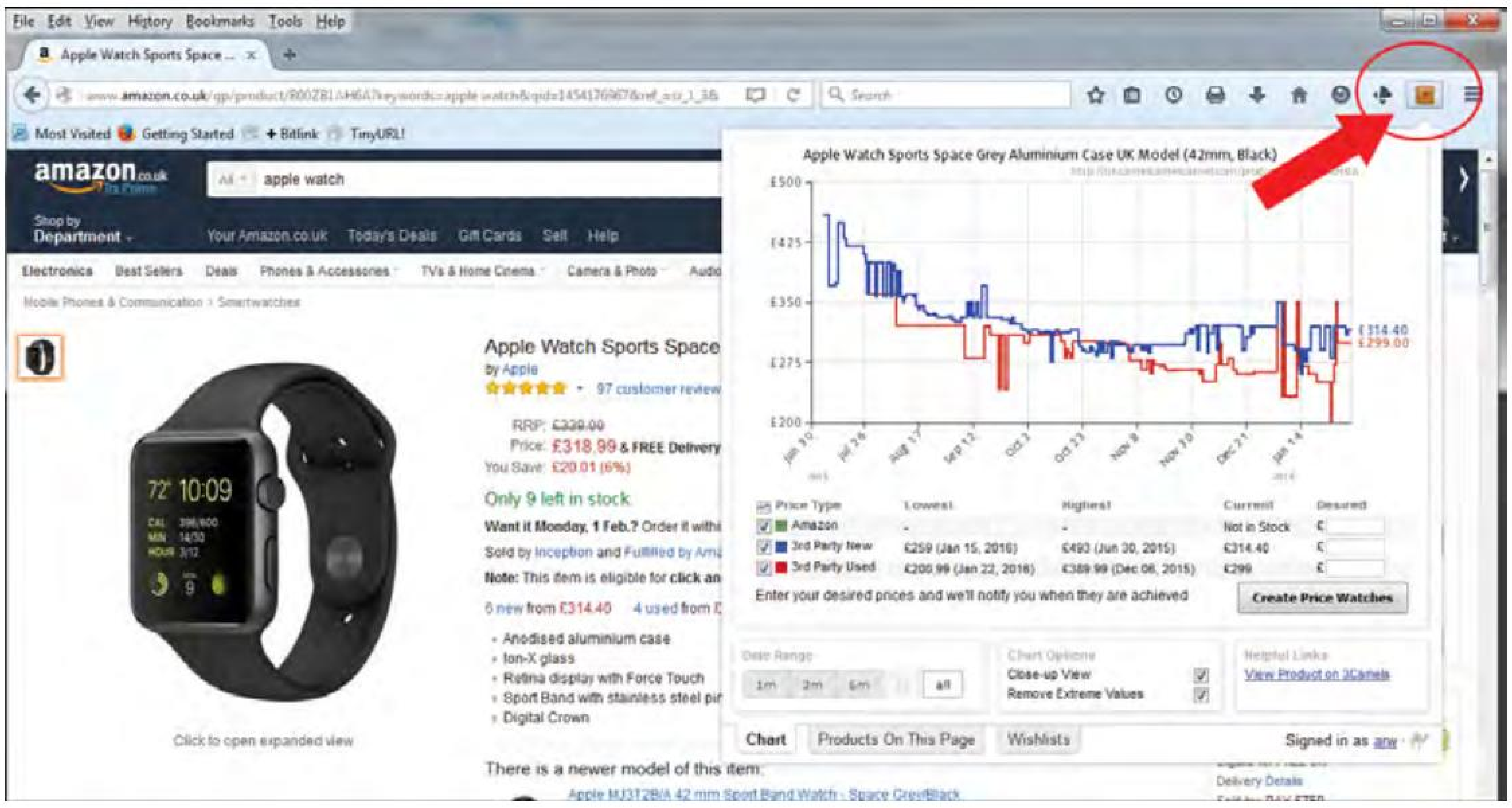
The ElectroDroid app contains a wealth of data for hobbyists, designers and students

Caught on cammy

Readers may recall my item on the UCam 247 1080p Wi-Fi IP outdoor camera, which can record images and video clips on internal SD cards or on a NAS, either wirelessly or via an Ethernet cable. Back to cloud services again: using a cloud-based system is an ideal application of remote storage and security monitoring, as it offers the option of checking images and receiving alerts while on the go from anywhere that has an Internet connection. An Australian cloud-based service called Cammy is compatible with it and, using IP cameras as sensors, Cammy promises to detect ‘real persons’ and not be triggered by false alarms from spiders, bugs or even friends that it recognises. Cammy ‘mailshotted’ a recent example of an actual case in



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The Camelizer for Amazon Shopping tracks product price trends and alerts of any reductions (Camelizer toolbar button arrowed)

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Micro SD

New UCam PVR needs a microSD card to record IP camera images. Its small form factor is easily hidden around the property.

the UK, when a user who was working away received an alarm on his phone to say ‘Person detected – dining room’. The homeowner’s internal camera had spotted a criminal lurking at the backdoor window and triggered the alarm, it is claimed. He was watching a live video view on his mobile phone, so with no-one at home he called the police and the villain was nabbed on the spot. A single Cammy indoor or outdoor camera with Cammy’s web-based service costs £7.50 a month, and you can subscribe at: **www.cammy.com**

I admit that my NAS tends to fill up too quickly with images captured by the UCam (10,000 maximum), but some smart criminals have been known to make off with disk drives containing CCTV footage anyway. More secure cloud-based hosting is an obvious choice if you want to subscribe to them, or for security you could FTP images onto your own server instead. UCam has now launched a palm-sized network recorder that can be hidden at home discretely out of harm’s way. It needs a micro SD card and can handle up to ten cameras, they claim. The one-off cost is £59.99 (excluding memory card) and is subscription-free. More details at: **www.amazon.co.uk/gp/product/B017R9WL6W**. For a setup that avoids any of the initial hassles, there is little doubt that a third-party cloud package like Cammy is likely to be a better choice, but the running costs must be born in mind. It’s a classic example of a useful and effective web-based service that avoids any of the thorny IT problems that a home network user is likely to encounter.

Last of all this month comes the news that the **Friends Reunited** website is closing down. Created in the year 2000 when the web was a very different place and social media didn’t really exist, the website’s header graphic was familiar to many of us. Its owners cite the upsurge in Facebook and social media, and Friends Reunited could not keep pace or attract new users. In due course a new site called **Liife** is opening. It’s claimed that Liife will be about ‘capturing key moments in our life and then sharing them with just the important people who actually took part in making them’. You can pre-register at **www.liife.com**. Users of Friends Reunited will still be able to log in and download their photos for a few months yet.

As you can see, life on the web is as hectic as ever, so join me next month for more news and updates from the web.

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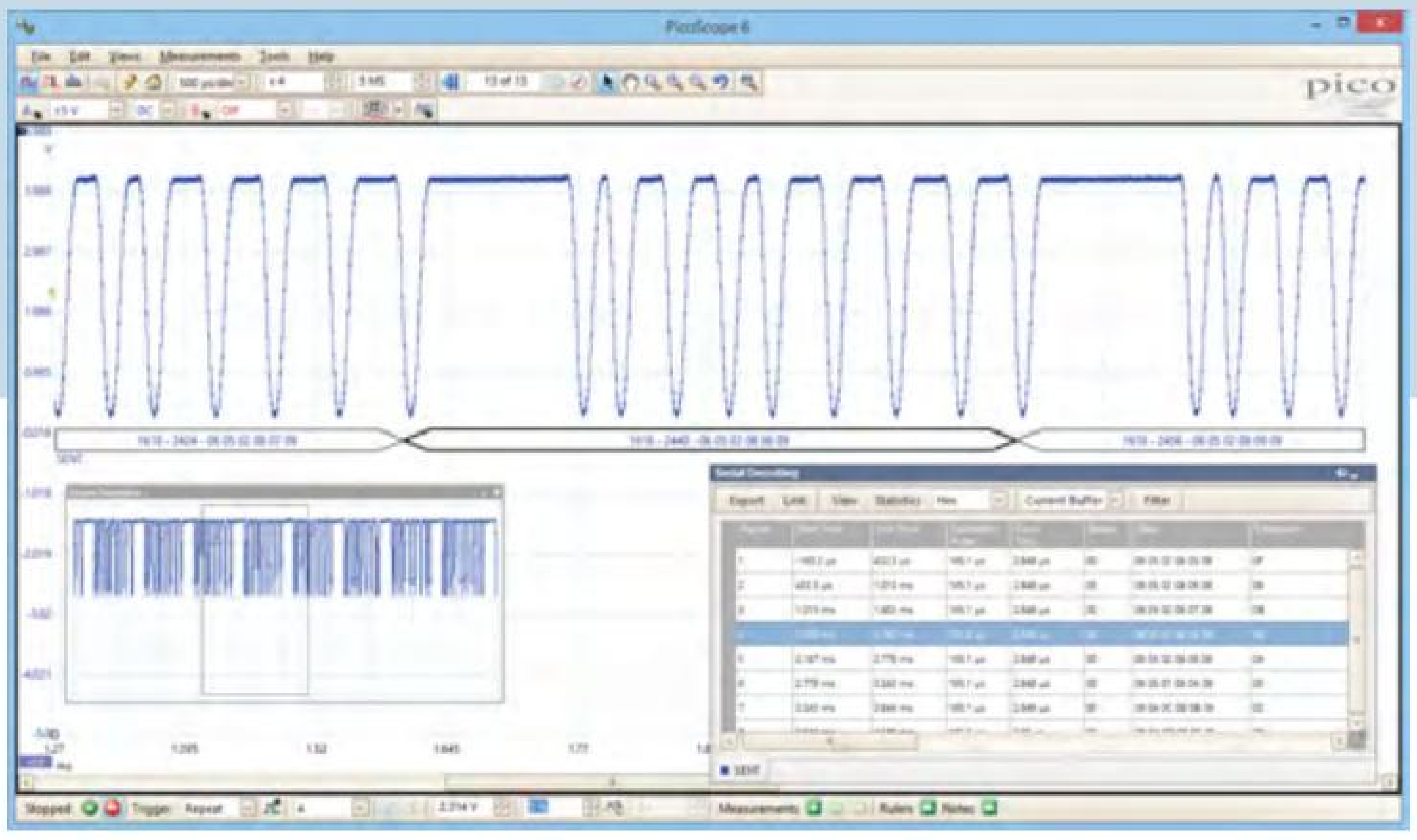

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By Robert Penfold

INTERFACE

Raspberry Pi capacitance meter

THE ORIGINAL intention for this month's *Interface* article was to feature a capacitance meter circuit that was essentially an analogue project from the distant past, but which would connect to a Raspberry Pi computer via an analogue-to-digital converter instead of simply driving a moving coil meter. This gave the setup outlined in the block diagram of Fig.1. The design is based on a monostable circuit that has the test capacitor as one section of the CR timing network, and several reference resistors in the other section. These resistors provide the unit with five measuring ranges.

The duration of the output pulse from the monostable is proportional to the value of the test capacitor, and the next part of the circuit has the task of converting pulse length into a corresponding voltage. This is achieved by feeding a capacitor from a constant-current generator during the output pulse. With the storage capacitor fed from a constant current source, the charge voltage rises at a linear rate, giving the required conversion from duration to voltage.

A very high input impedance buffer amplifier is used to ensure that the final charge voltage stored on the capacitor does not leak away while a reading is being taken, and the output of this stage feeds into an analogue-to-digital converter. The Raspberry Pi can then be used to measure the charge voltage, and convert this into a corresponding capacitance value. To take another reading, the storage capacitor is discharged by operating the Reset switch, and the monostable is triggered again via the Measure button.

Keep it simple

While this setup did actually work quite well, it has an obvious shortcoming. There are probably many circuits of yesteryear that could be given the same treatment, but would also run into the same problem. The final design works well enough, but it provides a rather complex and expensive solution to the problem. With a computer-based system it is possible to do clever things such as logging results and analysing them, but for general testing the original design with its analogue meter provides a better solution!

What is needed is a way of using the core concept of the original with its simple monostable-based design, while avoiding the need for conversions from a digital signal to an analogue one, and then back again. One solution would be to have a clock oscillator and a binary counter circuit. The monostable would be used to gate the clock signal, and the count obtained would then be proportional to the gate time, and to the value of the test capacitor. The Raspberry Pi would need to do nothing more than read the output of the counter and display the corresponding capacitance value.

Minimalism

It should be possible to obtain very accurate results over a wide range of values using this system, and it is one that I will probably return to at a later date. For the present design I tried simplifying things still further by using the built-in timing facilities of the Raspberry Pi and its supporting software. With this method it is simply necessary to have an output line to trigger the monostable, and an input line to monitor the output of the monostable. The computer then measures the time between the triggering of the monostable and the output pulse ending. This time is proportional to the value of the capacitor, and can be converted into a corresponding capacitance value.

The beauty of this system is that it requires only some very simple and inexpensive hardware. In fact, it does away with everything in the original system apart from the monostable and the range resistors! The only real drawback is that the timing facilities provided by the Raspberry Pi have limited accuracy. Using a Raspberry Pi to measure time has been covered before in *Interface* articles, and it will not be considered again in detail here, but the problem is caused by the use of interrupts. These take precedence over the timing software, and limit the accuracy that can be obtained. Even so, it is possible to obtain a high enough level of accuracy to permit reliable testing of a wide range of capacitors.

Old faithful

A 555 timer chip is used as the basis of the circuit. At one time it seemed as though this device was a feature of practically every electronic project, but it is not used to the same extent in modern electronics. However, it remains one of the most useful and versatile electronic building blocks, and it is cheap. Pin functions for the 555 timer chip are shown in Fig.2, and the block diagram for its inner workings is provided in Fig.3.

It is based on a potential divider that provides output voltages at one third and two thirds of the supply potential. There is also an S/R (set/reset) flip-flop, two voltage comparators, and an NPN transistor. In a monostable application the trigger input at pin 2 is normally held at or close to the positive supply voltage, and the device is triggered by taking it briefly below one third of the supply potential. The output at pin 3 then goes to

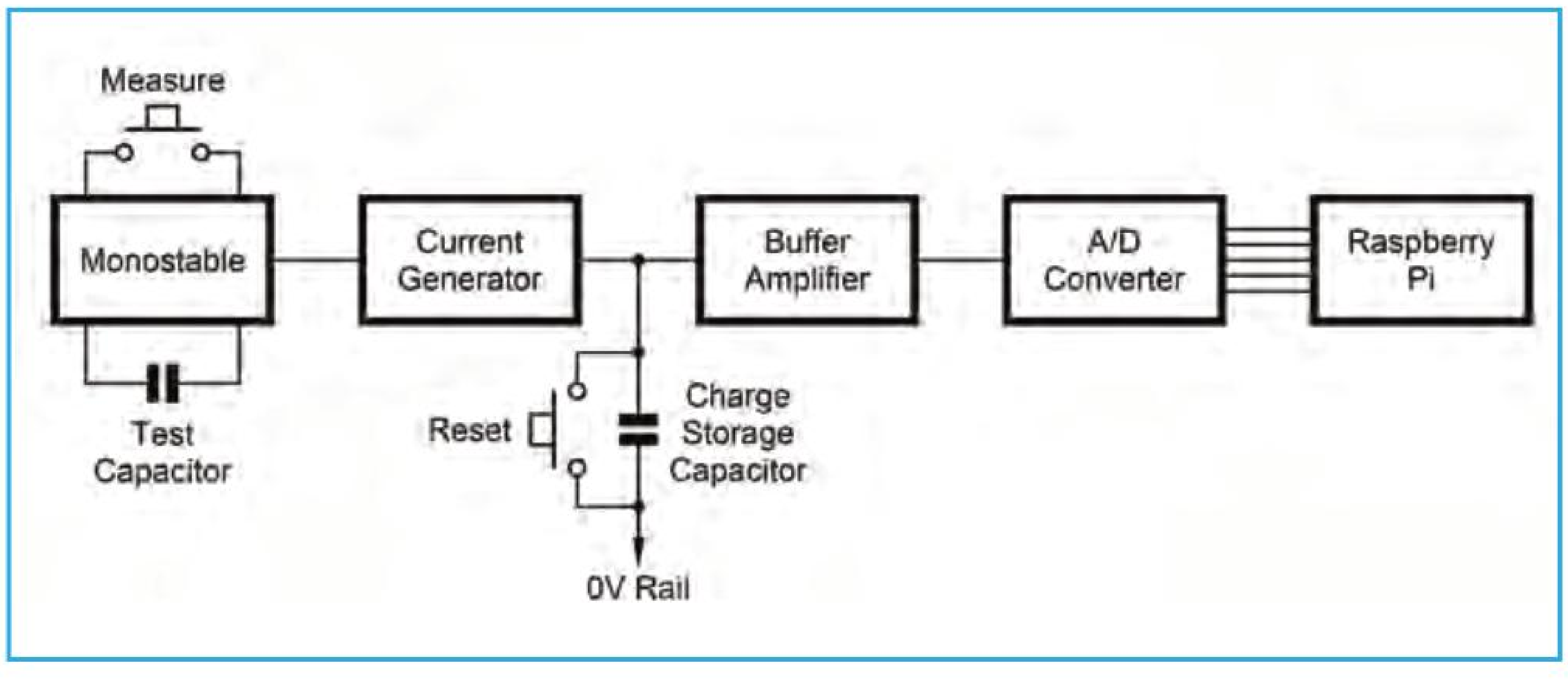


Fig.1. The original design was based on an old analogue capacitance meter circuit, using the system outlined in this block diagram. It worked, but it is a bit 'over the top'

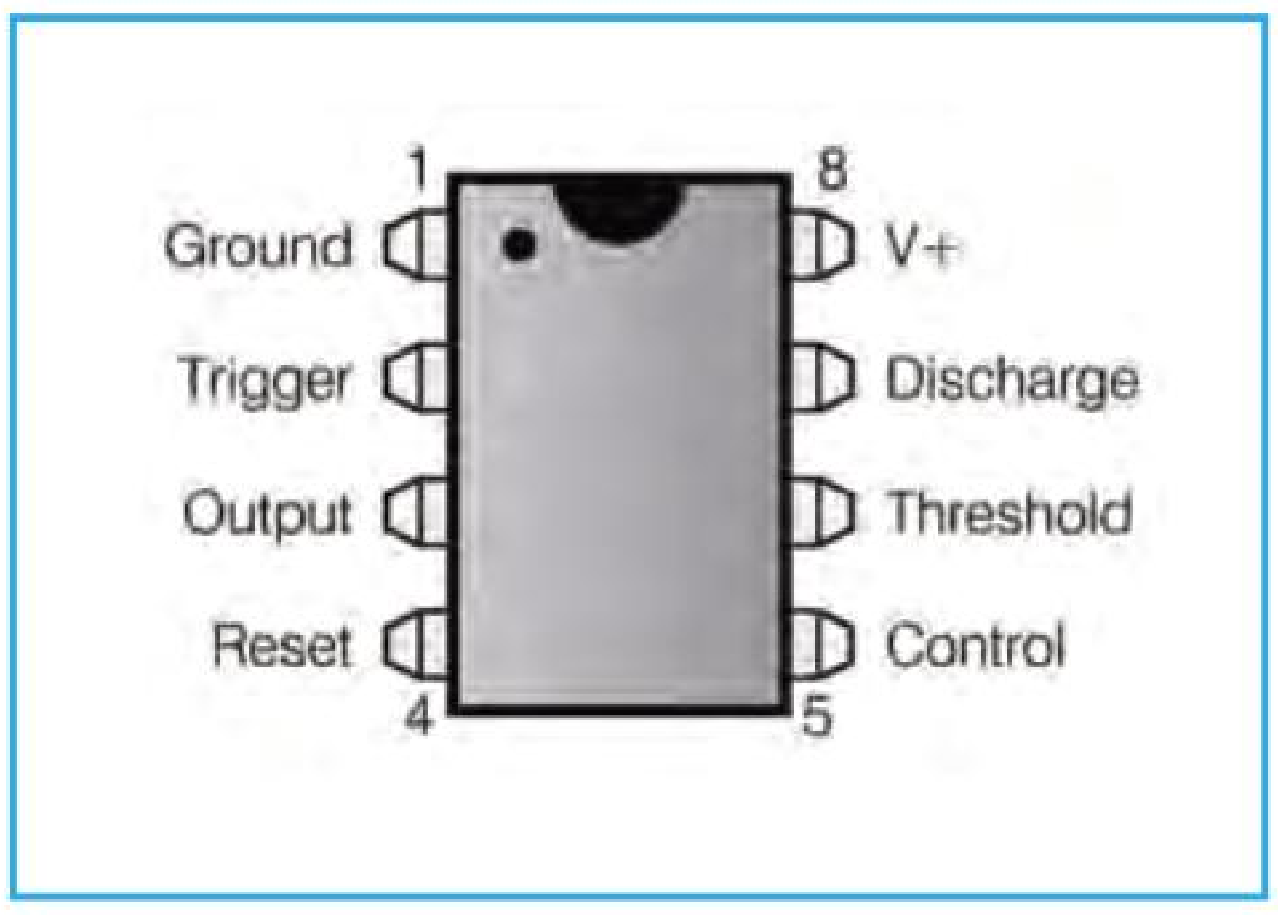


Fig.2. Pin functions for 8-pin DIL versions of the 555 timer chip

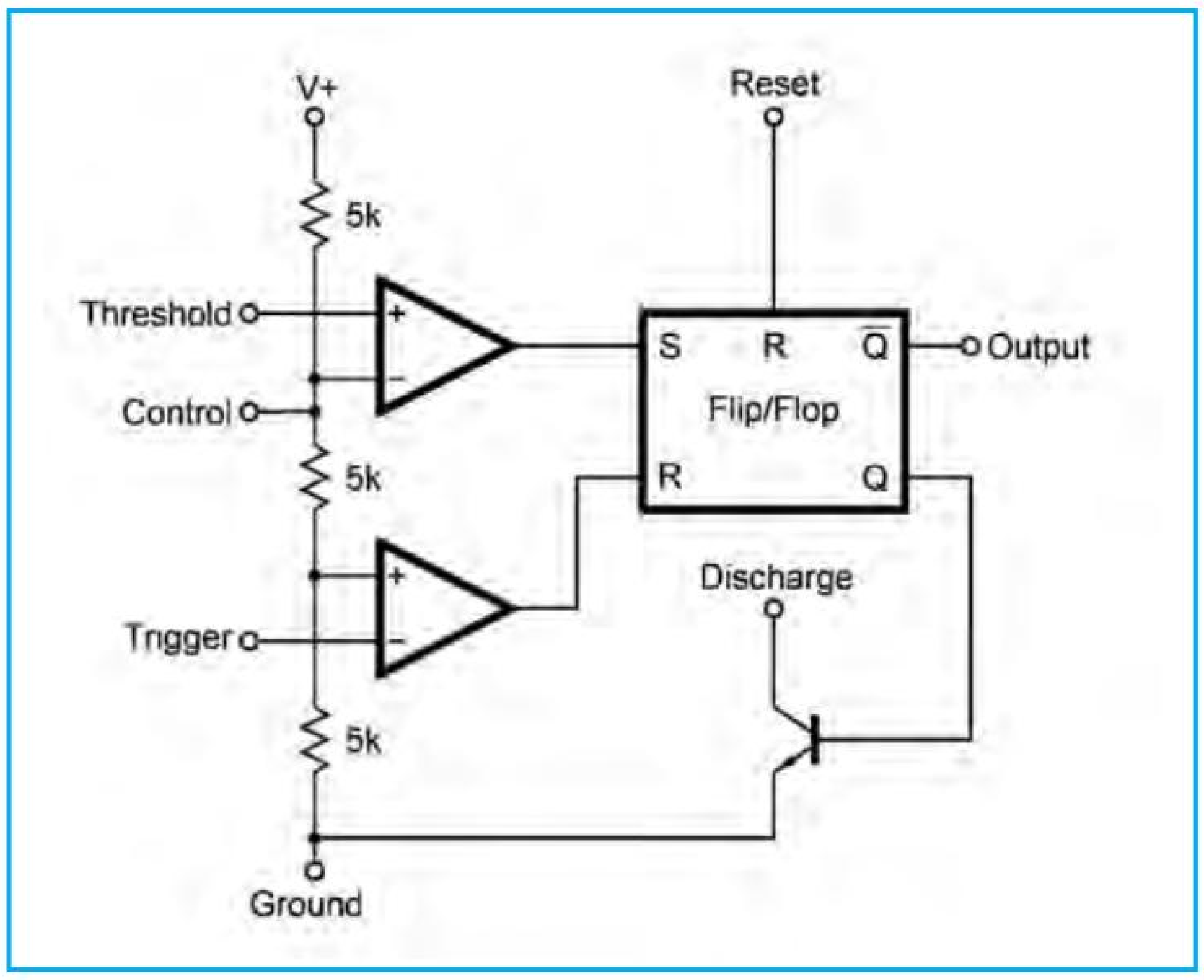


Fig.3. The internal arrangement of the 555 timer. Its simple method of operation gives output times that are independent of the supply voltage

the high state. The threshold and discharge pins (6 and 7 respectively) are connected together in a monostable circuit, and are fed from the CR timing network.

Under standby conditions the transistor at the discharge input holds the timing capacitor in a discharged state, but this transistor is switched off when the device is triggered. The capacitor then charges via the timing resistor until the charge potential reaches two thirds of the supply voltage. At this point the transistor at the discharge input is switched on again, rapidly discharging the timing capacitor, and the output pin returns to the low state. The device is then ready to be triggered again.

The control input at pin 5 connects to the part of the potential divider that provides the two thirds of the supply level reference. The output pulse duration is normally equal to 1.1CR seconds, but the pulse duration can be stretched by pulling the control input to a higher voltage, or reduced by pulling it to a lower level. Because the threshold levels of the device are certain proportions of the supply potential, rather than specific voltages, the actual supply voltage is not important. The output pulse duration is the same whether the supply is at 2V or 15V. In a monostable application the reset input at pin 4 is not usually required, and it is simply connected to the positive supply rail so that it is rendered inactive.

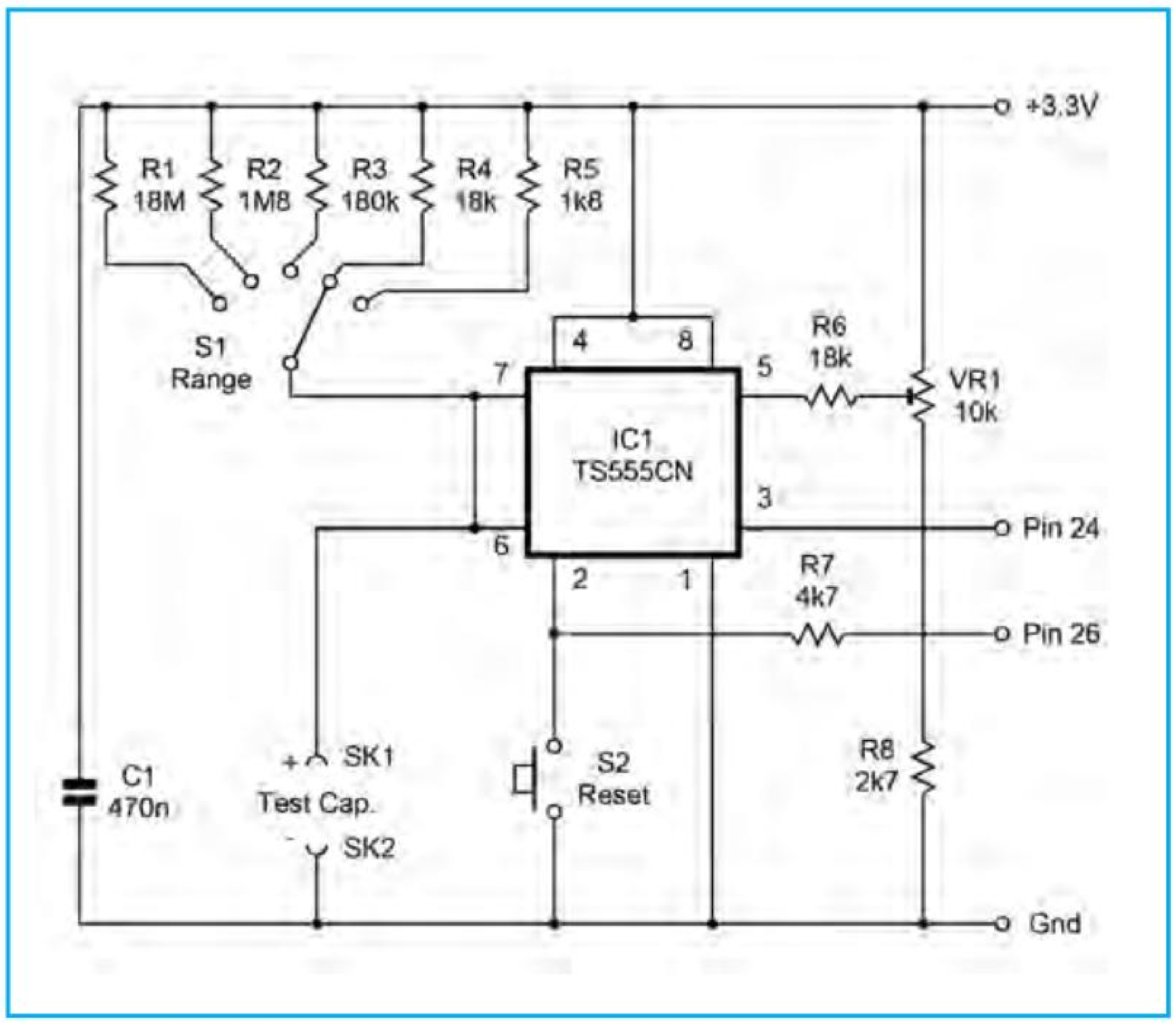


Fig.4. The circuit diagram for the capacitance meter interface. It is little more than a 555 monostable circuit, which is all that remains from the original design

Interface circuit

The circuit diagram for the capacitance meter interface is shown in Fig.4. S1 is the range switch, and it is used to select one of the five range resistors (R1 to R5). The notional full range values go from 1000µF on range 1 with R5 in circuit, down to 100nF with R1 as the timing resistor. As will become clear shortly, the software does not actually impose an upper limit on each range. Potentiometer VR1 is used to adjust the output pulse durations for calibration purposes. The output of IC1 is monitored by the GPIO 8 line at pin 24 of the port.

A trigger pulse for the circuit is generated on the GPIO 7 line at pin 26 of the GPIO port, and it is fed to the trigger input of IC1 via R7. S2 can be used to manually trigger the circuit and force the output to the high state. This is only necessary if the test device has no significant capacitance, and a proper output pulse is not generated. This could leave the software waiting indefinitely for the non-existent pulse to end. Operating S2 will then break the software from its hung-up state.

Components

A TS555CN is specified for IC1, and this is one of the improved versions of the original NE555 timer chip. It provides better performance than the original, such as lower current consumption and faster switching speeds. The most important improvement in the current context is that it will operate at supply potentials down to 2V, whereas the NE555 will not operate reliably with a supply of less than 4.5V. Using the TS555CN enables the circuit to run from the 3.3V supply that is available on the GPIO port, which enables it to interface directly to the input/output lines of the port. An ordinary NE555 will not work in this circuit, but other improved versions should be fine if they can operate at the low supply voltage used here. The improved 555 chips often use some form of MOS technology, and the normal anti-static handling precautions should be observed when dealing with them.

In order to provide good accuracy across all the ranges, resistors R1 to R5 should have a tolerance rating of 1% or better. It might be difficult to obtain an 18MΩ resistor for R1; if necessary the required value can be made up from something like 10, 1.8 and 6.2MΩ resistors connected in series. Ideally VR1 should be a good quality multi-turn preset resistor. This should give better stability than using a cheap preset, as well as making precise calibration a little easier. A 5-way switch for S1 might be difficult to obtain, but a 6 or 12-way type with an adjustable end-stop set for 5-way operation is just as good.

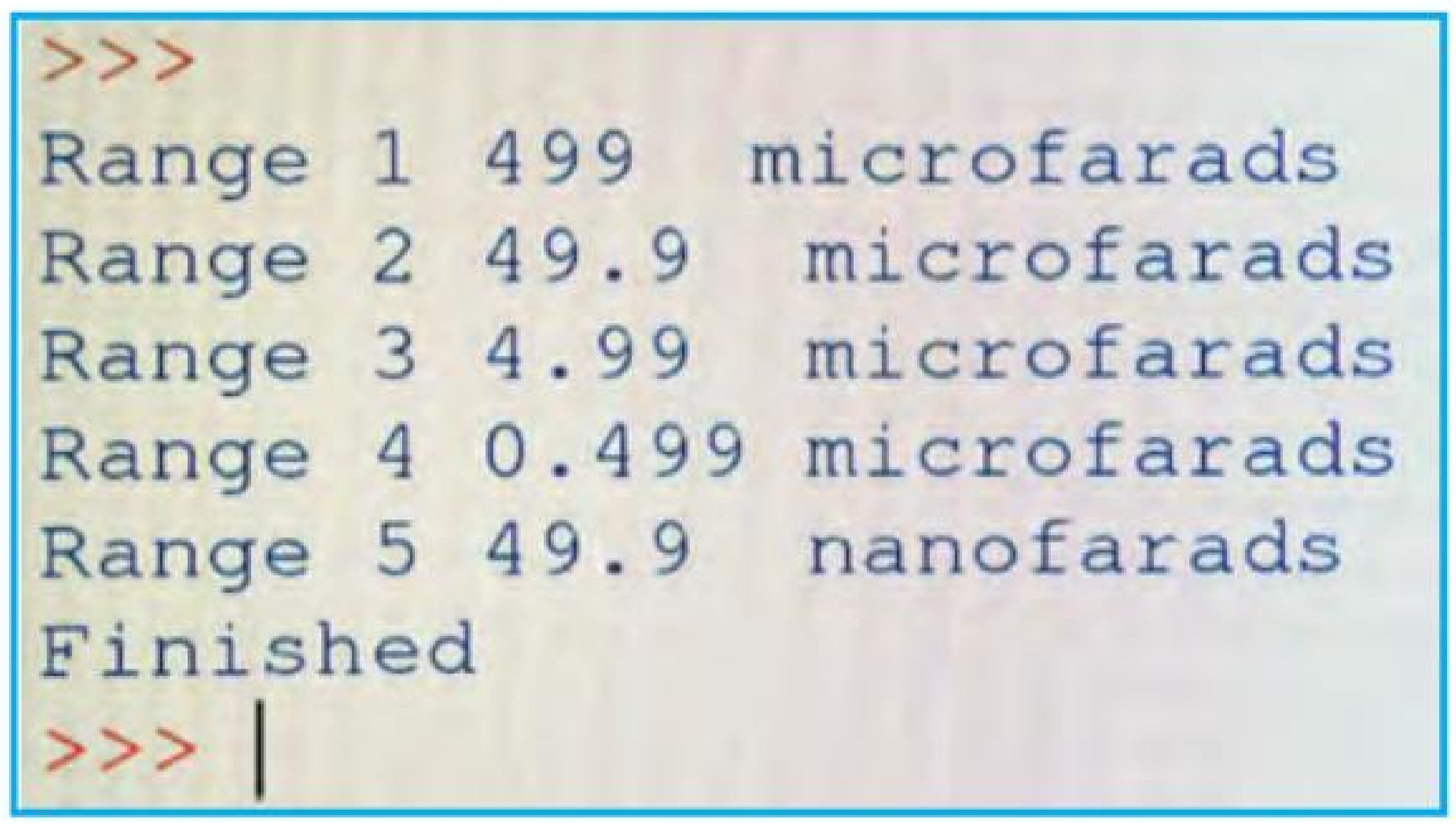
Software

The simple Python program provided in Listing 1 is all that is needed in order to take a reading from the capacitance meter interface. The initial part of the program sets things up in the normal way, but also imports the timing functions that are needed in this case. In the next section the input/output line at pin 24 of the GPIO port is set to operate as an edge-triggered input. The input/output line at pin 26 is set to operate as an output, and it is initially set at the high state.

At the beginning of the next section the trigger pulse is generated on the output line, and then the current value in the timer is stored in the variable called 'start'. The program then waits for a falling edge to be detected on the input line, or in other words, at the end of the output pulse from the monostable. The timer is then read again, and the returned value is store in the variable called 'end'. Deducting 'start' from 'end' gives the raw time value, which is stored in 'capval'.

The stored value is the time in seconds, and it usually runs to about a dozen or so decimal places. However, the accuracy of the timer only warrants three decimal places, if that. The value is multiplied by 500, which, ignoring any decimal places, gives a resolution of 2ms. With (say) a 1µF capacitor measured on range 3, the nominal output pulse duration would be 2s, and the final value therefore reflects the value of test components. It is just a matter of getting the decimal point in the right place for the units in use.

The rest of the program ‘does the math’, stripping any unwanted decimal places, and where appropriate, adding the decimal point at the appropriate position. It prints values for all five ranges, and it is therefore just a matter of looking at the one for the range in use (Fig.5).



```
>>>
Range 1 499   microfarads
Range 2 49.9   microfarads
Range 3 4.99   microfarads
Range 4 0.499 microfarads
Range 5 49.9   nanofarads
Finished
>>> |
```

Fig.5. The test result when measuring a 47nF capacitor on range 5

Calibration

A close tolerance capacitor is needed to calibrate the unit, and the capacitor should have a value of around 30% or more of the full-scale value of the range in use. Capacitors having a tolerance of 1% or better are not readily available at values of more than about 1µF, and being realistic about matters, this means that the unit will be calibrated on range 5. It is just a matter of using a bit of trial and error to adjust VR1 for good accuracy. The adjustment range provided by VR1 will probably be somewhat greater than is really needed. If accurate adjustment proves to be difficult, using a higher value resistor for R6 should ease matters.

For such a simple circuit the performance of the unit is quite good, but it is not suitable for testing low value components much below 1nF. On the other hand, it can handle very high values that are beyond the reach of most capacitance meters. With this system of capacitance measurement there is actually no upper limit to each range, but going beyond the specified upper limits will result in readings taking a relatively long time. A 4700µF capacitor can be accommodated by range 1 for example, but it will take nearly 10 seconds to take the reading. With something like a 2.2µF capacitor, better accuracy will be obtained by measuring it on the 1µF range instead of the 10µF range, but again, it will take a few seconds for the reading to be taken.

Listing 1

```
import RPi.GPIO as GPIO
import timeit
import time
GPIO.setmode(GPIO.BOARD)
GPIO.setwarnings(False)

GPIO.setup(24, GPIO.IN, pull_up_down=GPIO.PUD_UP)
GPIO.setup(26, GPIO.OUT)
GPIO.output(26,GPIO.HIGH)

GPIO.output(26,GPIO.LOW)
GPIO.output(26,GPIO.HIGH)
start = timeit.default_timer()
GPIO.wait_for_edge(24, GPIO.FALLING)
end = timeit.default_timer()
capval = end - start
capval = capval * 500
capvala = capval/1000
capvalb = int (capval)
capvalc = capval/10
capvald = capval/100

print ("Range 1", capvalb, " microfarads")
print ("Range 2", '%.1f' % capvalc, " microfarads")
print ("Range 3", '%.2f' % capvald, " microfarads")
print ("Range 4", '%.3f' % capvala, "microfarads")
print ("Range 5", '%.1f' % capvalc, " nanofarads")
print ("Finished")
```

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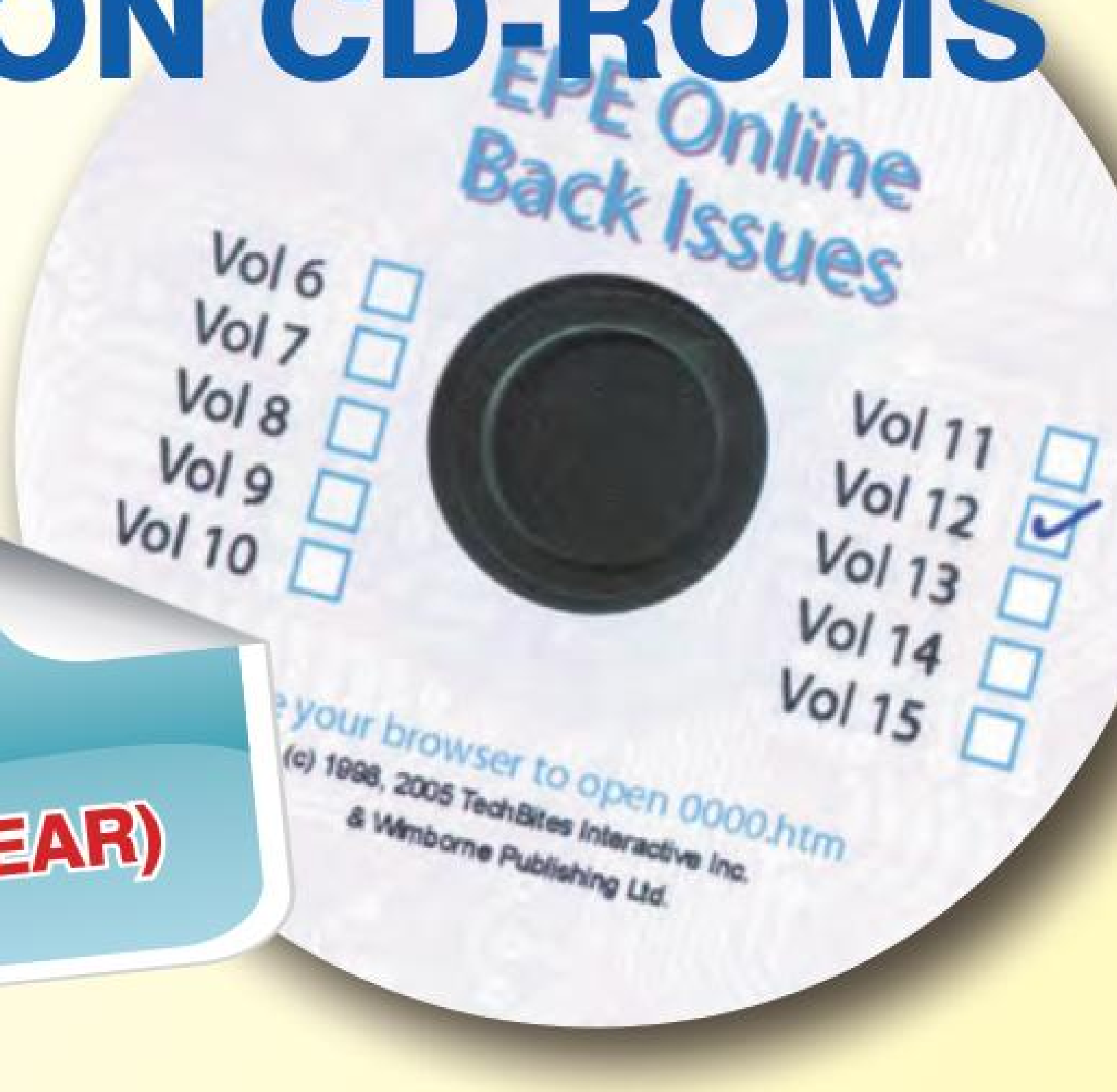
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PIC n' Mix

Mike O'Keeffe

Our periodic column for PIC programming enlightenment

Choosing and using accelerometers – Part 1

LAST MONTH, we looked at PIR motion sensors and how we use them in our everyday lives. This month, we're going to take a look at another widely used sensor, the accelerometer. You may not have seen one, but they exist all around us. They can be used in cars to detect collisions and activate airbags. They also feature in many smartphones. One of the commonest uses is the screen rotation feature, where the display orientation rotates based on what how the phone is held. I've often wondered about this ability of my phone, so I decided to look into it a bit more and really sink my teeth into the topic.

What exactly are these accelerometers and how do they work? To put it simply, accelerometers (obviously) measure acceleration, but that just begs the question – what is acceleration? Acceleration is the rate of change of velocity with respect to time. If an object changes its velocity then acceleration is involved. But, that also means *constant* velocity means *zero* acceleration – an object at rest or a cruising jet both have zero acceleration. Whenever 'acceleration' is discussed you quickly meet the term 'force', and the two are very intimately related by a simple equation: $F = ma$, where m is the mass of the object subjected to a force (F) and experiencing acceleration (a). I mention this because it goes to the heart of how many accelerometers work and in fact explains how they can be used to detect the orientation of a smartphone or tablet.

In the belly of the beast

Most accelerometers, and certainly the two types we will look at in this article are really force detectors that use a known mass to infer acceleration. They typically operate as a 'MEMS' (microelectromechanical system) that uses a capacitive or piezoelectric approach. A piezoelectric device contains a tiny piezoelectric crystal with a mass attached to it that is stressed when subject to compressive or stretching force. If you can measure the amount of force by measuring the amount of stress then you can infer the amount of acceleration. This is where the piezoelectric property of the material comes into play. A stressed piezoelectric crystal generates a voltage proportional to that stress; so, to cut a long story short, if you can measure the voltage across the crystal then you can quantify the acceleration.

An alternative – and more popular – method is the capacitive technique. Any two conducting surfaces separated by an insulator will behave as a capacitor. If the distance between the surfaces changes, then so will the capacitance. Imagine the surfaces are plates with one fixed plate and the other secured only at one end with a small mass at the other end – a bit like a flexible diving board with a person standing at the free end. Under acceleration, the tiny distance between the plates changes. From here, measuring acceleration becomes simply a question of measuring capacitance. Convert this to a voltage and we have a signal proportional to acceleration.

MEMS sound like rather complicated and hence expensive devices – the key to their affordability is that they are all constructed with the same lithographic technology used to manufacture integrated circuits. Mass production then makes them affordable devices. They even look like ICs – two are shown in the centre of the small PCBs shown in Fig.1

MEMS accelerometers typically come in two flavours – single-axis or three-axis devices. Space is three-dimensional, which means acceleration can be measured in any three dimensions, usually referred to as *x*, *y* and *z*, which are all at right angles to each other (see Fig.2). You can think of any two axes as defining a flat plane. For example *x* and *y*, just like the common coordinates used with graphs; *z* comes out of the paper on which the graph is drawn. Notice in Fig.1 that *x* and *y* are printed in the plane of the PCB and *z* is perpendicular to the PCB. A single-axis device only measures acceleration in one dimension, whereas a three-axis device is essentially three accelerometers in one package, measuring acceleration in all three dimensions simultaneously.

What to choose...

When choosing the right part to use, there are several parameters we need to consider, and with accelerometers it's not quite as simple as one might think:

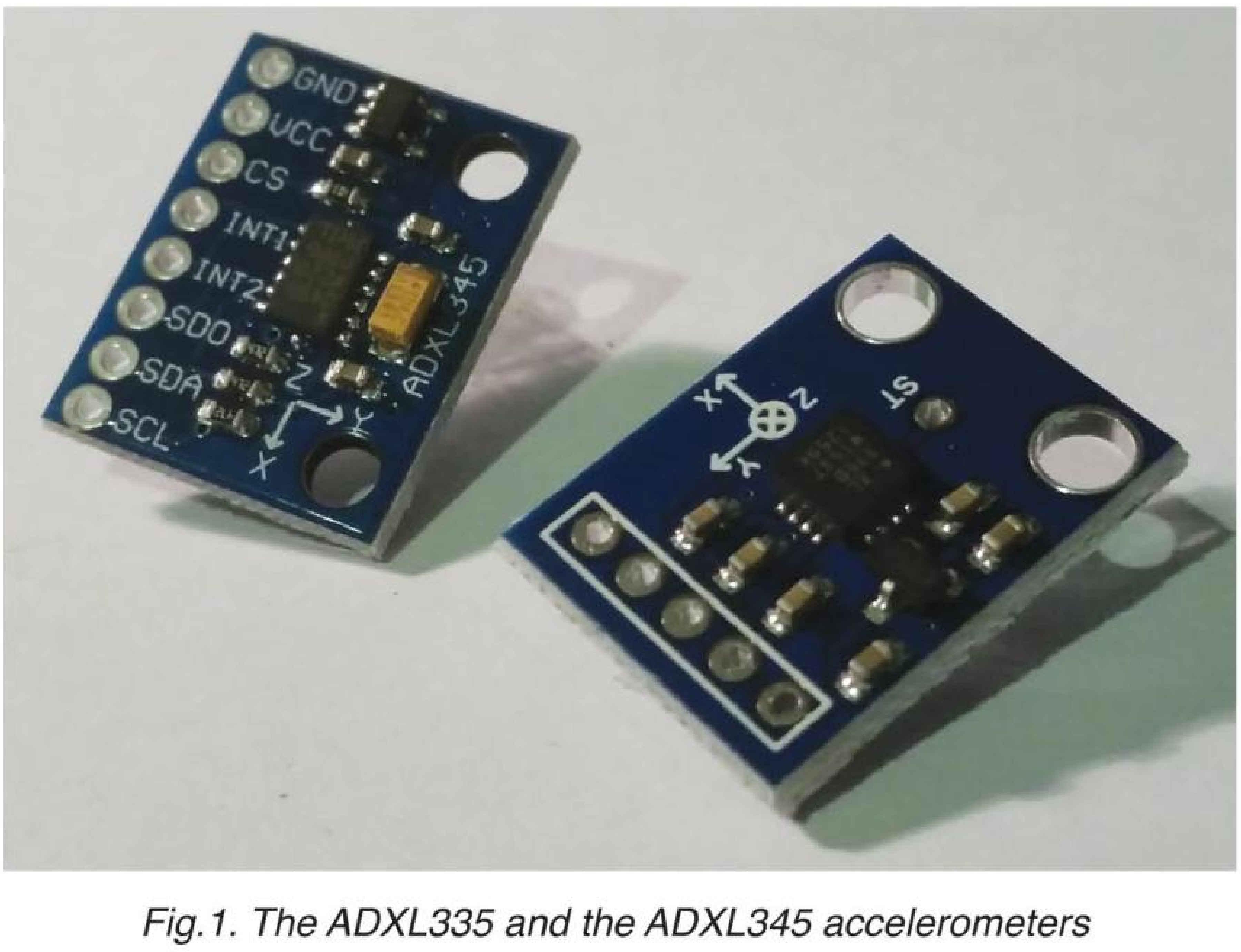

Fig.1. The ADXL335 and the ADXL345 accelerometers

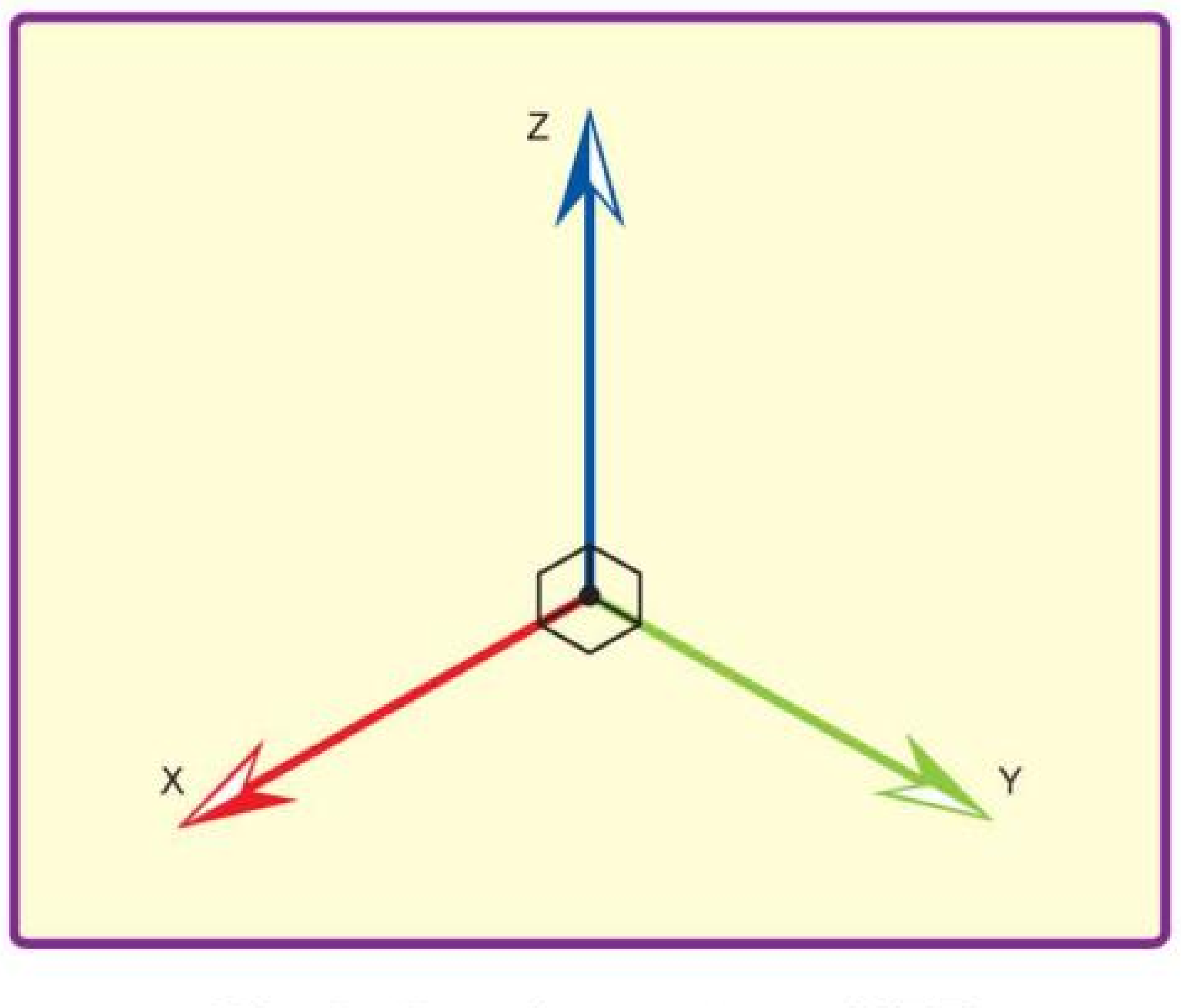

Fig.2. 3-axis space – XYZ

1) Analogue or digital
2) Number of axes
3) Maximum swing
4) Sensitivity
5) Bandwidth

Analogue or digital

We're going to look at two different accelerometers, both from manufacturer Analog Devices. The ADXL335 is an analogue accelerometer and the ADXL345 is a digital device. The analogue device outputs a voltage between ground and the operating voltage (which in this case is 3.3V). The digital option outputs data, formatted as 16-bit two's complement, accessible through either an SPI (3- or 4-wire Serial Peripheral Interface) or an I^{2}C digital interface. (There's actually another option that outputs data using pulse-width modulation (PWM) via a square wave with a known period – the duty cycle changes based on the acceleration experienced.)

Axes

The number of axes simply allows us to measure the acceleration in one, two or three dimensions. For most cases two axes is enough (acceleration on a flat plane), but if we need to measure axes in three-dimensional space then we'll need a three-axis device.

Swing

The 'swing' of an accelerometer is an important consideration when deciding which device to use. 'Swing' is measured in 'g's – that is, multiples of the acceleration due to gravity ($g = 9.81ms^{-2}$). If we want to measure tilt using the earth's gravity, then ±1.5g is more than enough. If we want to measure the motion of a car, plane or robot, ±2g should be plenty. If we want to measure sudden starts or stops, then we'll need ±5g or more. Accelerometers can measure from ±1g all the way up to ±250g, which you're unlikely to need unless you are designing some pretty advanced rockets. You can think of swing as the measurement range of the accelerometer.

Sensitivity

For an analogue accelerometer 'sensitivity' is the amount of output for a given acceleration, and as with all sensors, generally speaking, 'more is better'. For digital accelerometers we are more interested in the bit count. Higher resolution translates to greater sensitivity.

Bandwidth

The last thing to consider here is the bandwidth of the device. For example, if you want to monitor a vibrating structure.

Closely related to the accelerometer's bandwidth is the speed with which monitoring electronics (typically a PIC) can follow the accelerometer's output. If we check twenty times a second, our PIC's bandwidth would be 20Hz. That's usually fast enough for most applications, but if we want to measure vibration, we might need to increase our sampling frequency to a kilohertz or more. To put this in context, for an analogue input, our PIC18F27J13 has a sample rate of 100ksps in 10-bit-mode (100,000 samples per second with a resolution of 1024). Applying our Nyquist frequency (sample rate must be at least twice highest frequency), this sample rate would allow us to measure a frequency of 50kHz, which is plenty of room to measure anything we want. We won't really need to measure anything like that and we'll probably stick with just 50Hz, when we start to code.

Connecting it all up

Regular readers will know that I'm quite fond of the PIC18F27J13. It really is an easy 'go to' device when selecting a great, all-rounder PIC. This choice has only 'failed' me once when I needed to control a multiplexed four-digit, seven-segment display that needed control signals to the common and segment pins. These signals were controlling the segments by placing them in and out of phase with each other to illuminate each individual segment. This needed 1/3 V_{CC} and 2/3 V_{CC}, and it should have been possible using our regular go-to device… but it was getting more and more complicated. I eventually swapped to the PIC16F916, which handles these signals natively. I may cover this some other time as it was quite interesting and I learned a lot.

Back to accelerometers! In Fig.3, I've shown the schematic where I've connected up our two accelerometers to the PIC. This set up allows me to validate one device versus the other. The ADXL335 is connected to AN0, AN1 and AN2, the three ADC pins. This allows us to monitor the *x*, *y* and *z* axes simultaneously. I've added 10kΩ resistors in series with each of these signals for input impedance matching. We'll see how these work and change them if necessary when we start coding. The ADXL345 is accessed over an I^{2}C interface. All we need to connect here is the data and clock signals (SDA and SCL). Usually, we pull these two signals up to V_{CC} (or 3.3V in our case) with 10kΩ resistors, but this is only really needed when we have longer connections or we're connecting two I^{2}C interfaces on the one chain.

It's always a good idea to add a 100nF capacitor to any power input to stop high frequency noise coupling into devices, causing all sorts of unpredictable problems. I've left out the interrupt signals on the ADXL345 as well; I'm not interested in these at the moment.

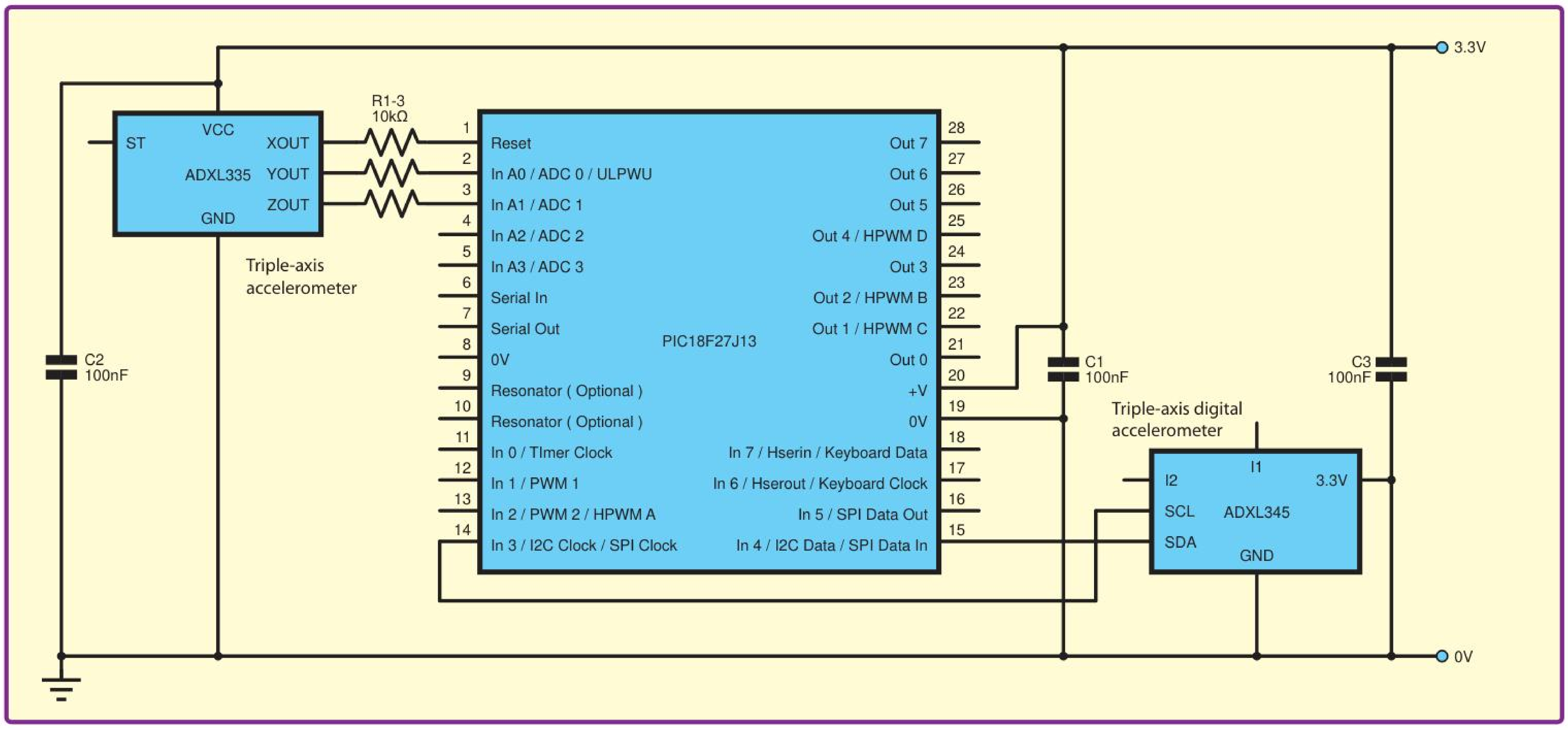
3.3V
0V
ST
VCC
XOUT
ADXL335
YOUT
ZOUT
GND
Triple-axis accelerometer
R1-3
10kΩ
C2
100nF
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Reset
In A0 / ADC 0 / ULPWU
In A1 / ADC 1
In A2 / ADC 2
In A3 / ADC 3
Serial In
Serial Out
0V
Resonator (Optional)
Resonator (Optional)
In 0 / TImer Clock
In 1 / PWM 1
In 2 / PWM 2 / HPWM A
In 3 / I2C Clock / SPI Clock
PIC18F27J13
28
27
26
25
24
23
22
21
20
19
18
17
16
15
Out 7
Out 6
Out 5
Out 4 / HPWM D
Out 3
Out 2 / HPWM B
Out 1 / HPWM C
Out 0
+V
0V
In 7 / Hserin / Keyboard Data
In 6 / Hserout / Keyboard Clock
In 5 / SPI Data Out
In 4 / I2C Data / SPI Data In
C1
100nF
C3
100nF
Triple-axis digital accelerometer
I2
I1
3.3V
SCL
ADXL345
SDA
GND

Fig.3. Analogue and digital accelerometer PIC schematic

Gestures

One of the more advanced uses of modern accelerometers is gesture capture. Gestures are a specific movement of a part of the body that the accelerometer is connected up to. Commonly used gestures are single tap, double tap, flick and many more. Capturing these can actually be quite difficult, involving signal filtering and mathematical algorithms. Fortunately, our digital ADXL345 already contains single and double tap recognition.

I've seen some interesting projects using accelerometers online, including but not limited to: wireless batteryless mouse, invisible pen, instant traffic collision notifier, simple smart watches and model rocket data logger.

Orientation

I mentioned earlier that our two accelerometers are really force detectors and that is how they detect smartphone orientation – time for an explanation. If you hold your smartphone vertically, rotate it 90° and then hold that position, the phone's software will reconfigure the display and rotate its content – how does it know how to do this? By now you've obviously realised it's something to do with an accelerometer – but surely just rotating a smartphone won't make much difference. Accelerometers are for linear, not rotational motion. The answer is gravity. Remember the little masses that squash the piezoelectric material or bend our 'diving board' variable capacitors? These will experience a force due to gravity and by determining which one of the three axes experiences the most force you can work out the orientation of the smartphone. This is why the accelerometer is really a force detector. Even when both your smartphone and its accelerometers are stationary (zero velocity, zero acceleration) it is the force due to gravity that is being detected.

Movement and feedback

Last, but not least, a small digression. Measuring and creating motion often go hand in hand, so let's have a quick look at a couple of methods of creating physical feedback. (This subject really doesn't deserve a whole article to itself, but a sideline is enough.) The most popular feedback methods use an LRA (low-resonance actuator) or ERM (eccentric rotating mass). These are commonly used in smartphones and gaming consoles to recreate the sense of touch by applying force, vibration or motor to the user. The LRA's operate using a piezoelectric disk that vibrates when a current is passed through it. The ERM is basically an off-centred weight attached to a motor; this causes vibration and is much stronger than the LRA. Unfortunately, the ERM needs an AC signal to be driven correctly, which means a dedicated driver, instead of being driven by a GPIO pin. You can actually drive either of these from a dedicated IC, which is recommended in order to optimise their lifetime, improve power usage and optimise control and strength of vibration.

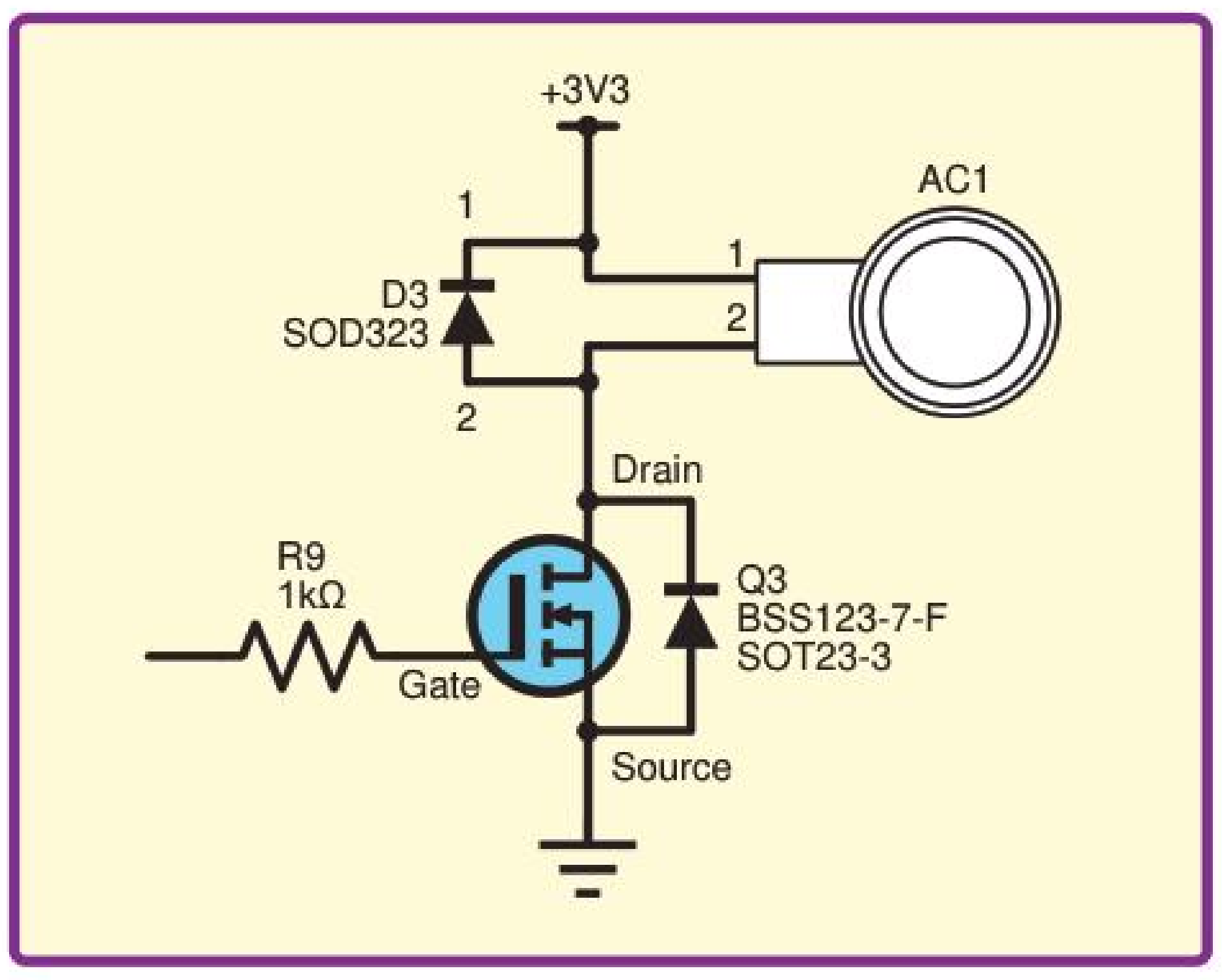

Fig.4. Schematic basic LRA driver

See Fig.4 for a straightforward connection and control of an LRA vibrator. Here we're using an 8mm-diameter 308-107 LRA from Precision MicroDrives; a low-side N-type FET (BSS123), a 1kΩ gate resistor (not completely necessary), and a reverse-biased diode for protection across the LRA. We could add a current-limiting resistor in series from the source to ground to limit the strength of the LRA, but we don't want to limit it too much. This LRA is rated for 3V and 72mA – we're running it at only 3.3V, which should be just about right. This means a current-limiting resistor of 47Ω (approx 3.3V/72mA), so it can never use more than it's technically rated for. This would be a safe option.

That's about all we need to look at for vibrator motors at the moment, I might write more about it again if there's any demand for it, but it really is straightforward enough.

Next month

Of course, we're not done yet – now we need to discuss how we actually get useful information back from the accelerometers. Next month, I'll discuss setting up the analogue-to-digital conversion inputs and access over I²C or SPI. Space allowing, I may 'touch upon' capturing gestures like the single and double tap. Much to look forward – see you next month!

Not all of Mike's technology tinkering and discussion makes it to print. You can follow the rest of it on Twitter at *@MikePOKeeffe*, up on *EPE Chat Zone* as *mikepokeeffe* and from his blog at *mikepokeeffe.blogspot.com*

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CIRCUIT SURGERY

REGULAR CLINIC

BY IAN BELL

Voltage references – Part 2

LAST MONTH, we started looking at voltage references, which are circuits that aim to produce a fixed, accurate and precise output voltage. The fixed voltage is used to provide a reference against which input signals can be correctly measured; for example, by an analogue-to-digital converter (ADC). They are also used as a reference against which the level of output signals can be correctly set, for example by a digital-to-analogue converter (DAC) or voltage regulator. References are also used to provide accurate bias voltages in various type of analogue circuit. Voltage references are therefore of critical importance to many electronic systems, particularly in high quality measurement systems.

We discussed accuracy (also called trueness) and precision in some depth last month. Accuracy refers to how close a reference's average output voltage is to the specified value. Precision refers to how much variation occurs in the output voltage at any given instant. Over the short term, such variations may be due to electrical noise; over longer periods it may be due to ageing processes (drift). Output voltages also vary with environmental factors, with temperature usually being the dominant factor (semiconductors are very temperature sensitive). However, other factors, such as mechanical stress, may also alter the output voltage of a reference.

In high performance systems it is usually precision that is more important than the initial accuracy of the reference. This is because the system can be calibrated to reduce or remove most of any initial inaccuracy, and once this has been done it is the precision that determines the ongoing quality of the system.

Last month, we discussed the basic principles of voltage references, the meaning of accuracy/trueness and precision and, in the light of this, and the key datasheet parameters of voltage references, output voltage, operating current, initial accuracy/tolerance, temperature coefficient, thermal hysteresis, high and low frequency noise, and long-term stability. This month, we will look in more detail at reference devices and circuits.

Fig.1 shows the two basic types of voltage reference – two-terminal, or shunt references, and three-terminal or series references. The input voltage (V_{IN}) is usually the power supply. Capacitors are often connected across the outputs of voltage references to reduce high frequency noise, although some systems may use more sophisticated filters. Datasheets often provide guidance for capacitance values or other filters to use.

Zener diodes

The simplest form of two-terminal reference is a Zener diode (see Fig.2). When a small reverse bias is applied to a diode, only a very small leakage current flows. As the reverse voltage is increased, this current remains very small until a certain voltage, known as the breakdown voltage (which varies with different diodes). At breakdown, the current increases very rapidly for very small further increases in applied voltage. This can be seen in the characteristics of a 4.7V Zener diode, shown in Fig.3. Breakdown is not damaging to the diode as long as the current flowing is limited (typically by an external resistor, as in Fig.2). The maximum safe current depends on the individual diode and its environment. It is the heat from the power dissipation due to high current flow which causes damage, not the breakdown process itself.

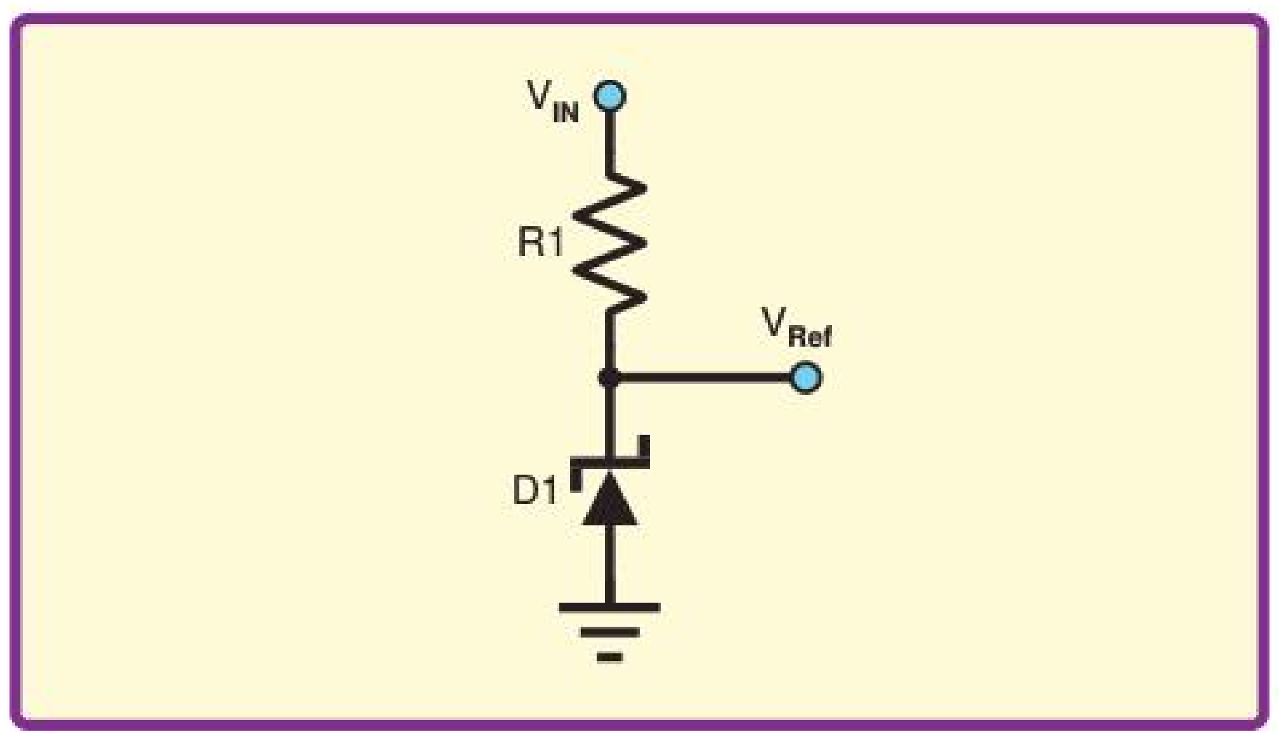

Fig.2. A Zener diode reverse biased into breakdown is a simple two terminal (shunt) voltage reference

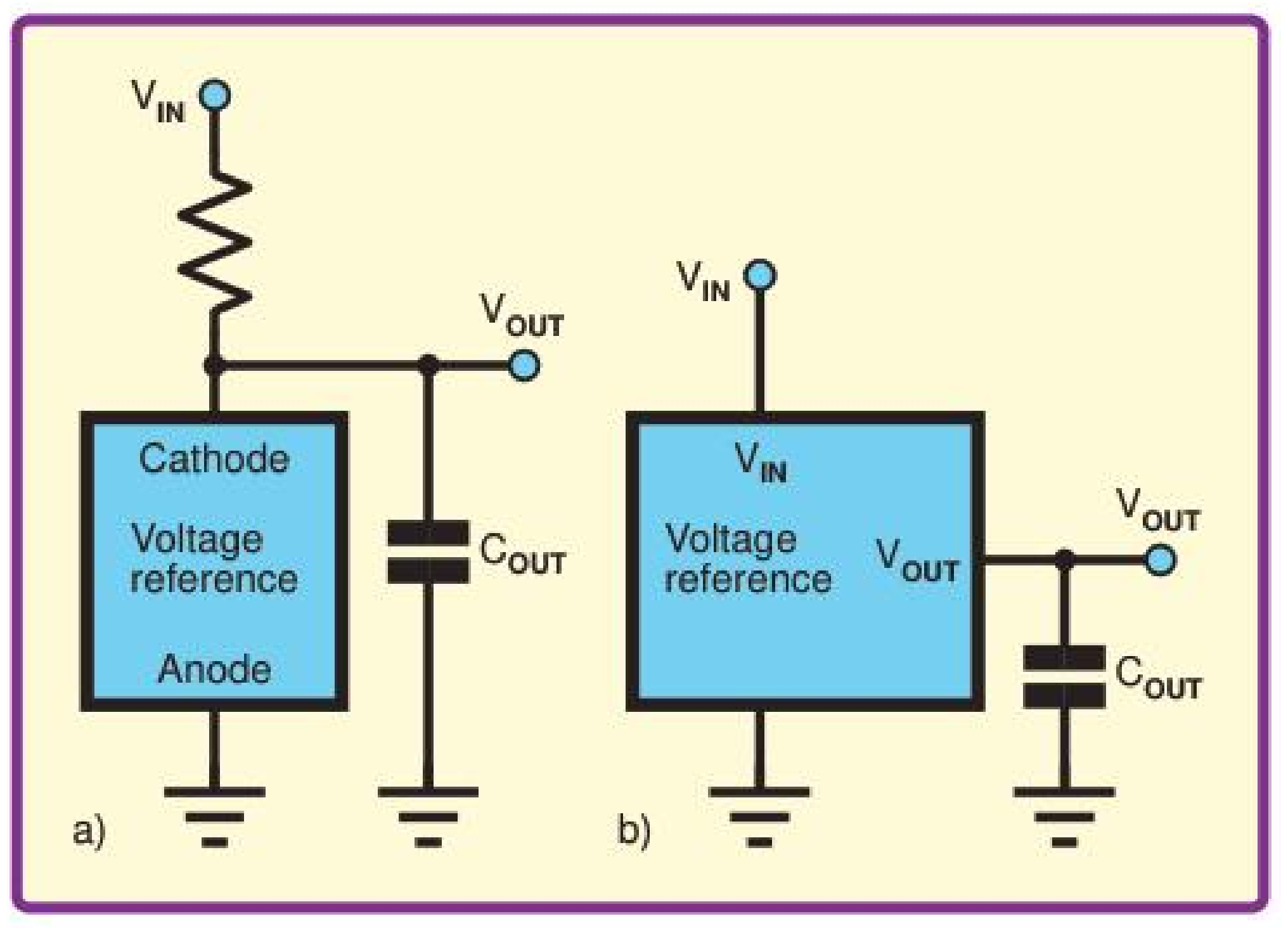

Fig.1. Voltage reference configurations: (a) two-terminal reference. (b) three-terminal reference

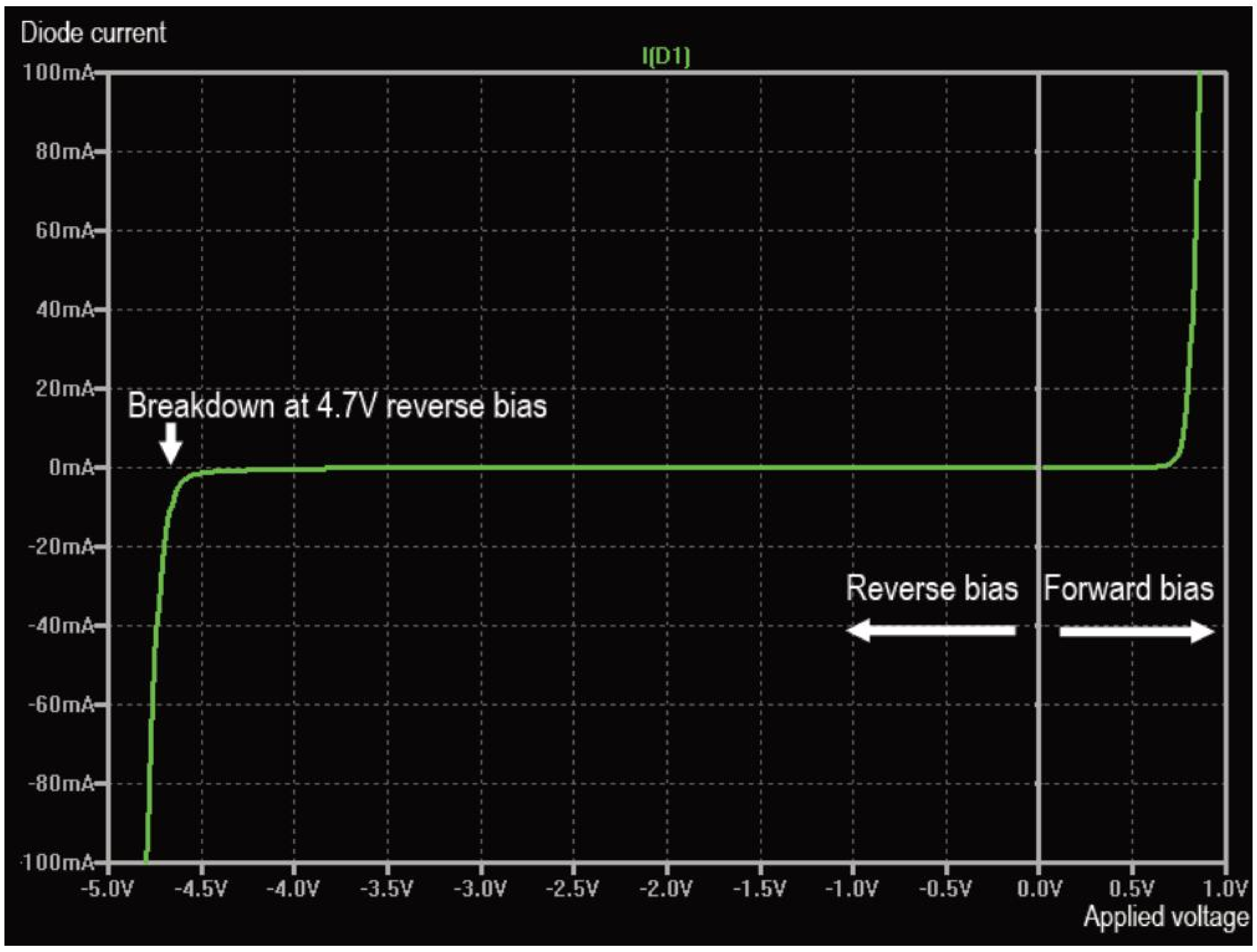

Fig.3. Characteristics of a 4.7V Zener diode (current against applied voltage)

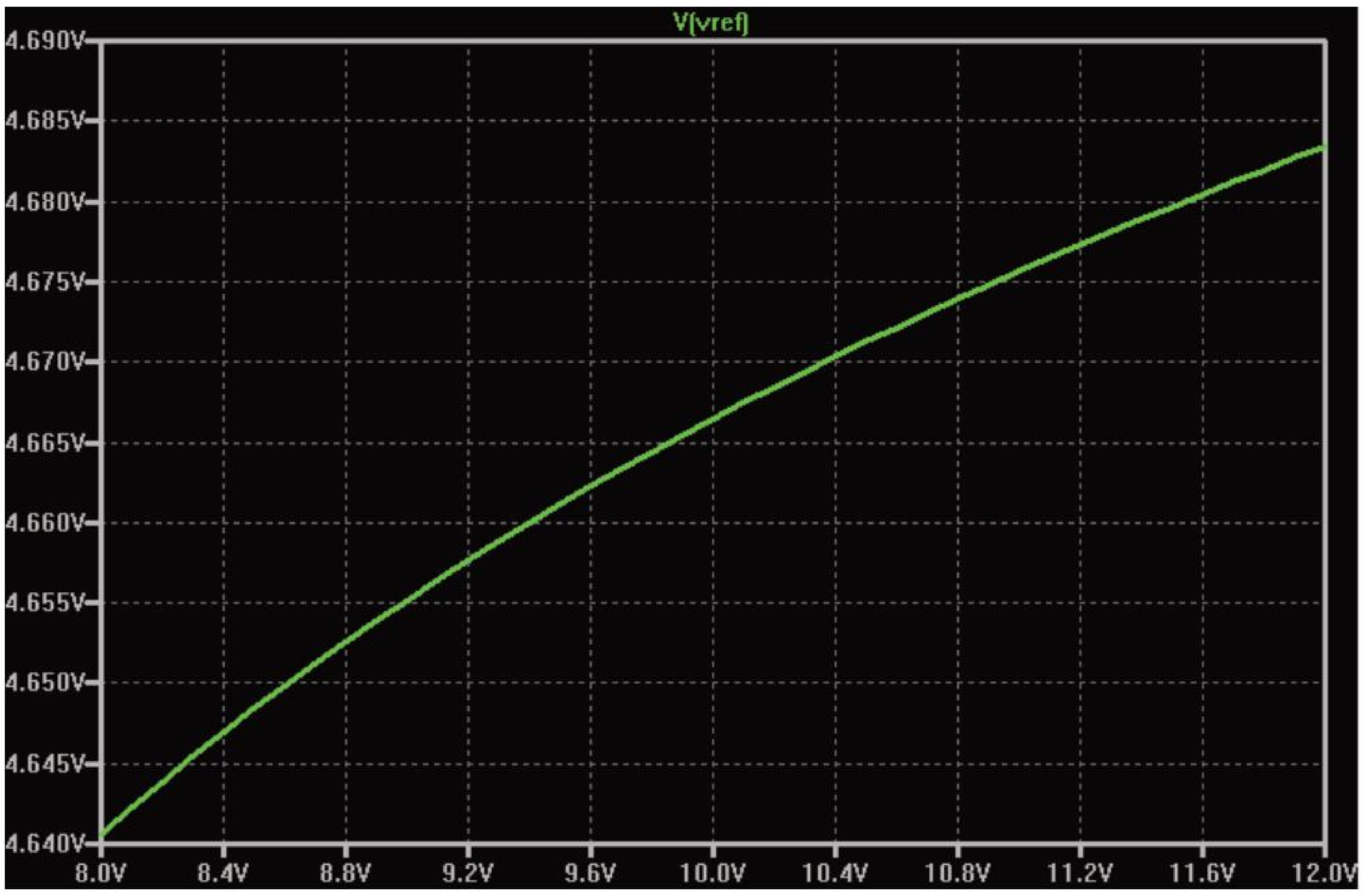

Fig.4. Variation of V_{Ref} with V_{in} for the diode in Fig.3 in the circuit in Fig.2 with R_1 = 500Ω

To use a Zener diode as a reference we apply reverse bias through a resistor, as shown in Fig.2. The resistor is chosen so that the diode is operating in breakdown, but within its maximum current rating. If the current in the diode varies, the very steep slope of the characteristic curve in breakdown means that the voltage will only change by a very small amount. In a typical application, V_{IN} will be the supply voltage and so will not vary very much, and even quite large variations in V_{IN} will only cause a moderate change in V_{REF}.

The variation in V_{REF} with V_{IN} is illustrated in Fig.4. This result is for a diode with the characteristics shown in Fig.3 used in the circuit in Fig.2 with R_1 = 500Ω. As V_{IN} ranges from 8.0V to 10.0V (a 4V change) V_{REF} only varies by 44mV. Actually, it is really the current change in the Zener which is of importance here, and which directly causes the change in V_{REF}. In this example the Zener current changes by about 8mA (6.7mA to 14.8mA).

Although the relative change in V_{REF} with V_{IN} may seem quite small in this example, it is not up to the standard of some other reference devices. For example, the LM399 precision shunt reference from Linear Technology (**linear.com**) produces an output voltage change of typically 6mV for a 9.5mA current change (0.5mA to 10mA, its operating range). The LM399 has two connections, which electrically 'look' like a Zener, indeed it contains a Zener, but the actual circuitry is more complex to provide the improved performance.

Variation of operating current is not the only issue that we have to worry about – as already mentioned, variation of reference voltage with temperature is a major concern. When dealing with Zener diodes we need to understand the effect of temperature on reverse breakdown. There are two different mechanisms by which breakdown occurs – avalanche and Zener breakdown. Despite this, most diodes designed for use, or operated, in breakdown are commonly referred to as Zener diodes.

Breakdown

In avalanche breakdown, as the applied reverse voltage is increased the charge carriers acquire more and more energy, because the increasing electric field strength results in increased acceleration. At some point this energy becomes sufficient to release new charge carriers (hole-electron pairs) when the carriers collide with the crystal lattice of the semiconductor. This is known as the avalanche process. The released carriers can also produce further carriers by the avalanche process, resulting in high current flow.

In Zener breakdown the electric field in the diode junction causes quantum mechanical tunnelling to occur, allowing a reverse current to flow through the junction. A given diode may undergo either avalanche or Zener breakdown, and in some cases both may occur simultaneously. Zener breakdown tends to occur in more heavily doped junctions and at voltages below about 5V or 6V. Avalanche breakdown tends to occur in more lightly doped junctions and at voltages above about 5V or 6V.

The breakdown voltages of a diode under both avalanche and Zener breakdown exhibit quite large temperature coefficients. Zener breakdown voltage decreases with increasing temperature, whereas avalanche breakdown voltage increases with increasing temperature. However, if both mechanisms are active there can be a point at which the temperature coefficients cancel out and the breakdown voltage remains (nearly) constant with temperature. This is typically around 5V to 7V.

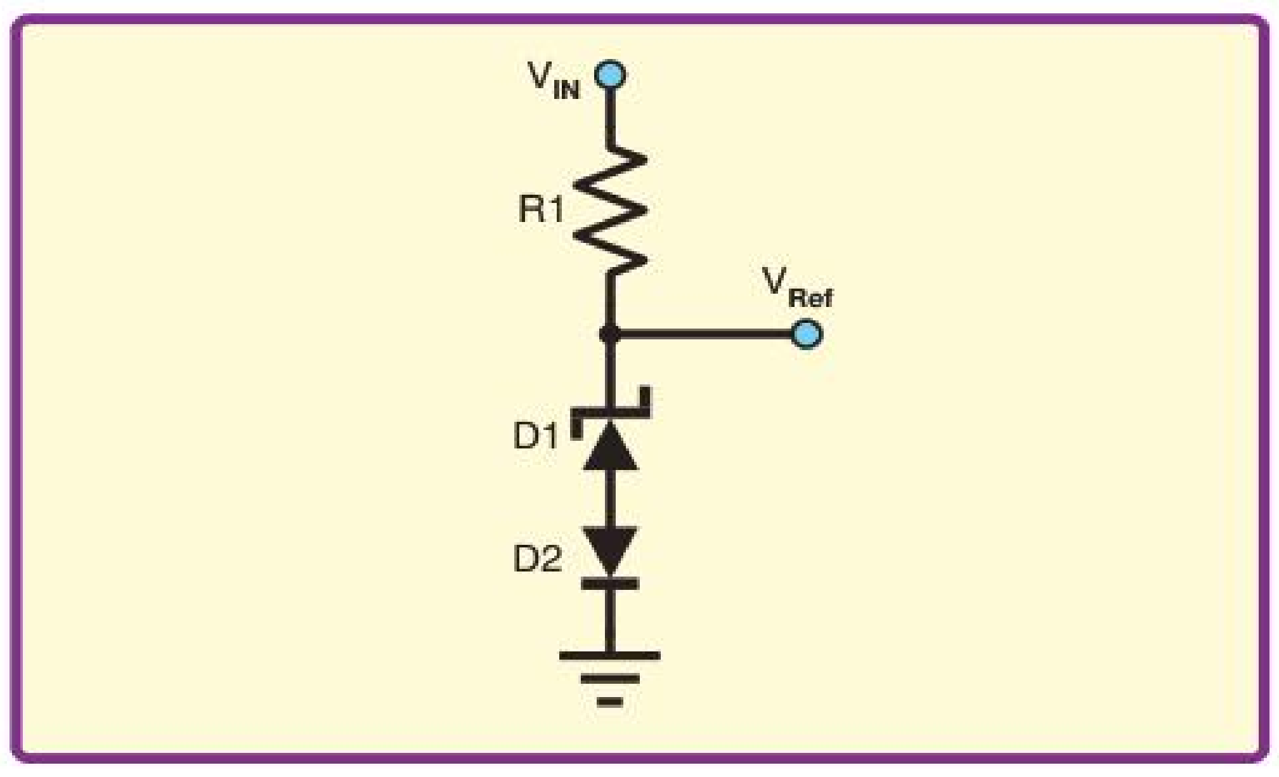

Fig.5. Compensated Zener diode

Compensated

Instead of trying to arrange for the Zener itself to have a zero temperature coefficient, the positive temperature coefficient of a Zener diode (in avalanche breakdown) can be compensated by the negative temperature coefficient of the voltage drop across a forward-biased PN junction from a diode or transistor. This arrangement is known as a compensated Zener diode and is shown in Fig.5. This circuit is more likely to be found inside a reference IC than available as a basic component in its own right. However, there are a few examples, such as the 1N4565 to 1N4585 range of 6.4V temperature-compensated references from Microsemi (**microsemi.com**), at least some of which are currently available from Digikey (**digikey.com**). The best temperature coefficients for devices in this range are about 5ppm/°C.

Heated

Another approach to reducing the effect of external temperature variation is to take control of the device's temperature directly by heating it in a controlled way to keep its temperature constant. This is the approach used in the previously mentioned LM399, which in addition to its 'Zener' terminals has two heater connections. The heater is controlled by an on-chip temperature stabiliser, enabling the LM399 to achieve a temperature coefficient of around 0.5ppm/°C for its 6.95V nominal output. The initial accuracy is 2%, so calibration would usually be required in high accuracy designs. This device costs around £8 for single devices at the time of writing, which is more than many other references, but it is not the most expensive.

The LTZ1000 (from Linear Technology) also uses a Zener-based circuit heater and can provide even better performance (7.2V at 0.05ppm/°C), but it is expensive, at around £35 to £50, and like all very high precision references requires extra careful design of surrounding circuitry and physical layout to benefit from its full capabilities. Examples of the kind of problems that you might not initially think of are the thermocouple effects at the junction between the leads and PCB adding to the 'tempco', or even the airflow around the circuit affecting the thermocouple effect and generating additional low frequency noise. Mechanical stresses during

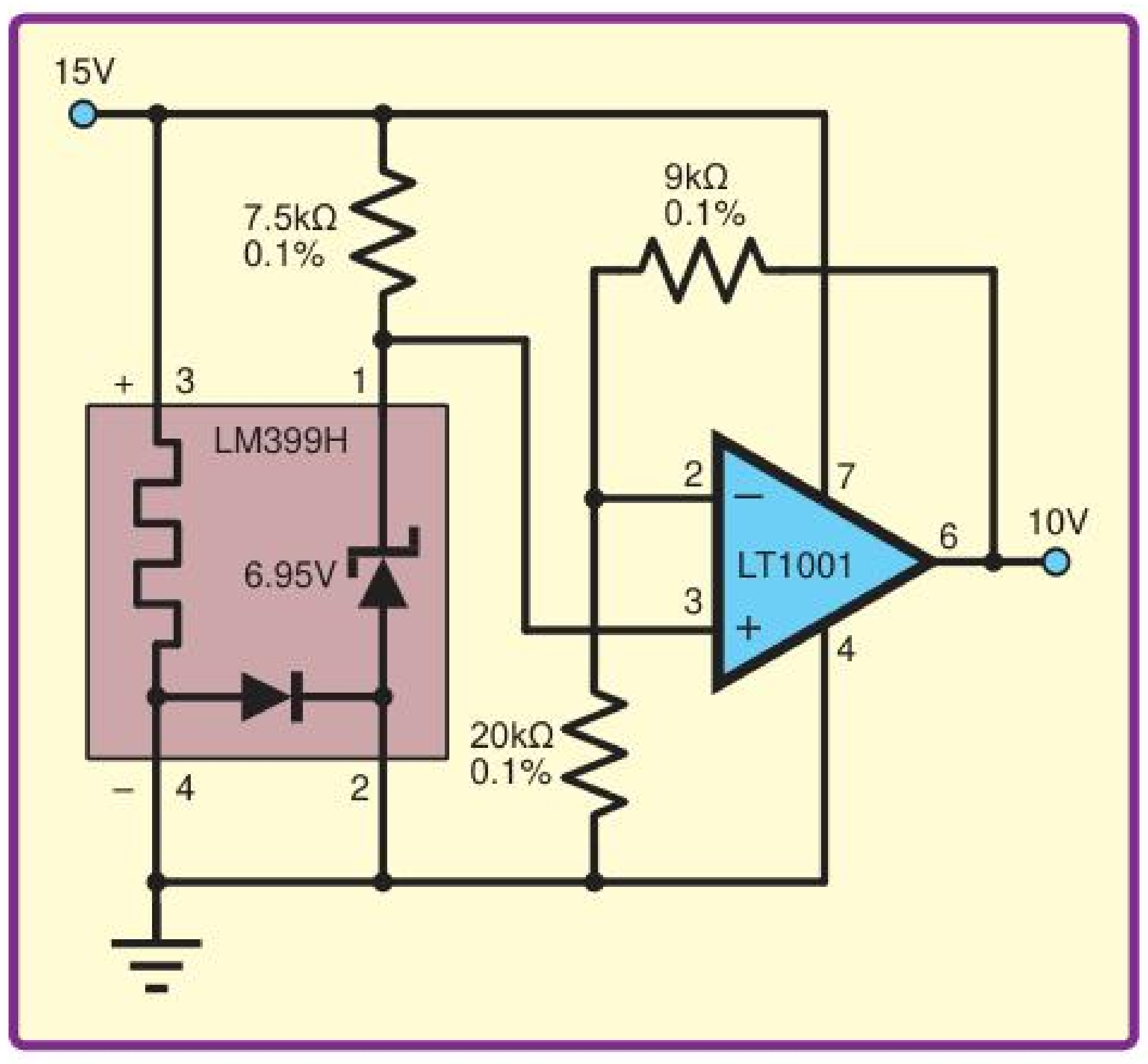

Fig.6. 10V buffered reference circuit from LM399 datasheet (**linear.com**)

board construction can degrade device performance. You really do have to think of everything to design really high precision systems!

Three terminals

Two-terminal references, with or without heaters, may require external buffer/amplifier circuits to prevent loading of the reference and/or to convert the reference voltage (as in Fig.6). An alternative is to use a three-terminal Zener-based reference, which typically includes an on-chip buffer/amplifier to provide more output current and convenient output voltages (round numbers like 2.5V and 5V and 'power of two' values like 2.048V (2^{11}mV) and 4.096V (2^{12}mV). Lack of on-chip heaters also reduces power consumption. There are a large number of three-terminal references, although not all them use Zener-based circuits.

One Zener-based example, which has good temperature coefficient performance, is the MAX6325/MAX6341/MAX6350 range from Maxim Integrated (maximintegrated.com). These provide 2.5V, 4.096V and 5V respectively at typical temperature coefficients down to 0.5ppm/°C (1ppm/°C worse case for the best grade). Again, this good performance comes at a cost, with prices of approximately £10 to £20 depending on temperature coefficient grade (different grades are available).

Burying noise

Noise is another issue that must be considered for voltage references. Reverse-biased diodes and Zeners are known for being noisy – noise generator circuits often use Zener diodes. This would seem to make them unsuitable for high quality references, but obviously they are used. The problem is overcome by using what is known as a buried Zener (or subsurface Zener diode) in which the breakdown region is covered with a protective layer. Most of the noise produced by an ordinary Zener occurs due to mechanical stresses and crystal imperfections near the surface of the device. Burying it greatly reduces these effects and also improves the long-term stability of the device.

Buried Zeners typically have voltages in the range 5V to 7V, where, as we noted earlier, temperature coefficients are the lowest. The datasheets for the Zener-based voltage reference devices mentioned so far (LM399, LTZ1000 and MAX6325) all state the use of subsurface/buried Zeners.

Zener diodes are not the only way of creating a reference voltage. Another common approach is the bandgap reference. The basic concept behind the bandgap reference is to add two voltages with opposite temperature coefficients to try to get a zero temperature coefficient output voltage. This is similar in principle to the compensated Zener and the crossover point between Zener and avalanche breakdown discussed earlier. Individual semiconductor characteristics vary with temperature, but we can contrive to produce two opposite variations that cancel out.

Band theory

Before describing a bandgap circuit we will very briefly describe the theory behind the name. The term 'bandgap' refers to the physics of electrical conduction. The band gap is the difference in energy required by an electron in a solid to break free from the atoms in the structure of a material and become available to take part in electrical conduction. The term 'band' refers to the fact that electrons associated with the outer layers for the atom have a range of possible energy values (called the 'valance band') and electrons taking part in electrical conduction have a range of possible energy values (called the 'conduction band'). The term 'gap'refers to the fact there is range of 'forbidden' energy values between the valance and conduction bands.

To take part in conduction an electron must receive enough energy to cross this forbidden gap. The gap is large in insulators, small in semiconductors and very small in conductors. Bandgap *energy* is measured in electron volts (eV). If we divide this value by the change of one electron (1.602×10^{-19}C) we get the bandgap voltage. The output voltage of a bandgap voltage reference, typically about 1.26V, is related to the bandgap voltage of silicon at absolute zero, around 1.2V.

Bandgap

Returning to the principle of the bandgap circuit, we will note that one of the voltages with opposing temperature coefficients is simply the V_{BE} voltage of a bipolar transistor. This is relatively straightforward to obtain – we just bias a transistor into conduction. The V_{BE} voltage has a negative temperature coefficient (about −2mV/K), so to cancel it we need a voltage with a positive temperature coefficient of the same magnitude as the negative V_{BE} tempco.

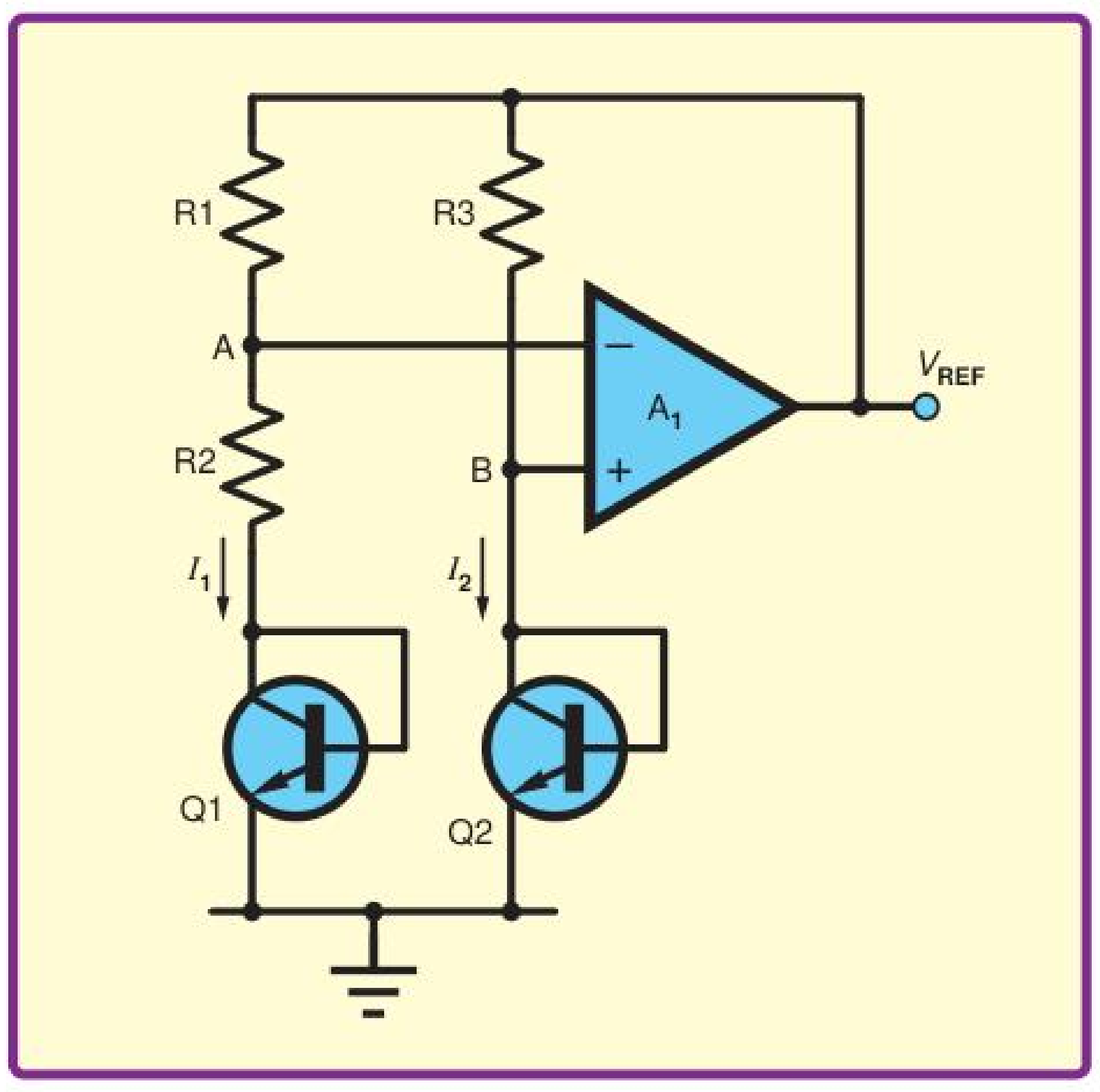

Fig.7. Bandgap reference circuit

This positive temperature coefficient voltage is obtained from the difference between the V_{BE} voltages of two transistors operating at differing current densities. This voltage is 'proportional to absolute temperature' (PTAT) and if scaled correctly can be used to cancel out the V_{BE} tempco.

A basic bandgap circuit is show in Fig.7 (this is a concept rather than a full design). The operational amplifier A_1 is providing a negative feedback loop which controls V_{REF} to make the voltage at point A equal to the voltage at point B (make its input voltages equal). Given this assumption, the base-emitter voltage of Q_2 is equal to the base-emitter voltage of Q_1 plus the voltage drop across R_2, which is I_1R_2. So the difference in base-emitter voltages of the two transistors, ΔV_{BE}, is:

$$\Delta V_{BE} = V_{BE2} - V_{BE1} = I_1 R_2$$

Transistor equations

We can relate the emitter current, I_E, of a bipolar transistor to its base-emitter voltage, V_{BE}, using the basic form of the Ebers-Moll equation:

$$I_E = I_S \exp\left(\frac{qV_{BE}}{kT}\right)$$

where I_S is the reverse saturation current of the base-emitter diode, which is a property of the individual transistor, q is the electronic charge (the charge on one electron, which is a physical constant), k is Boltzmann's constant (another physical constant), and T is the absolute temperature (in kelvin).

This equation can be rearranged to give the base-emitter voltage:

$$V_{BE} = \frac{kT}{q} \ln\left(\frac{I_E}{I_S}\right)$$

In which 'ln()' is the natural logarithm function, the inverse of the exponential function. The difference in the two base-emitter voltages in the circuit in Fig.7 can therefore be written:

$$\Delta V_{BE} = \frac{kT}{q} \ln\left(\frac{I_2}{I_{S2}}\right) - \frac{kT}{q} \ln\left(\frac{I_1}{I_{S1}}\right)$$

We are subtracting two logarithms, which is equivalent to dividing by the subtracted value inside the logarithm. So we can write:

$$\Delta V_{BE} = \frac{kT}{q}\ln\left(\frac{I_2}{I_{S2}} \bigg/ \frac{I_1}{I_{S1}}\right) = \frac{kT}{q}\ln\left(\frac{I_2 I_{S1}}{I_1 I_{S2}}\right)$$

Equal voltage

In the circuit, given that the voltages at points A and B are equal, the voltages across R_1 and R_3 are also equal, so we can write:

$$I_1 R_1 = I_2 R_3$$

Therefore: $$\frac{I_2}{I_1} = \frac{R_1}{R_3}$$

Substituting this into the equation for ΔV_{BE} we get:

$$\Delta V_{BE} = \frac{kT}{q}\ln\left(\frac{R_1 I_{S1}}{R_3 I_{S2}}\right)$$

The voltage across R_2, which is I_1R_2 is also equal to ΔV_{BE}, therefore we can write:

$$\Delta V_{BE} = I_1 R_2$$

Therefore: $$I_1 = \frac{\Delta V_{BE}}{R_2}$$

The same current (I_1) flows in R_1, so the voltage across R_1, which is $V_{R1} = I_1R_1$ and which is also equal to the voltage across R_3 (V_{R3}) is:

$$V_{R1} = V_{R3} = \frac{R_1}{R_2}\Delta V_{BE} = \frac{R_1}{R_2}\frac{kT}{q}\ln\left(\frac{R_1 I_{S1}}{R_3 I_{S2}}\right) = GT$$

We can say the voltages across R_1 and R_3 are equal because they are connected together at one end the other ends are at points A and B which, as we have already observed, have equal voltage thanks to the amplifier's feedback.

PTAT

In the above equation everything is fixed (resistor values, transistor saturation currents) or a physical constant (k and q), except T. So, V_{R3} is directly proportional to absolute temperature (PTAT), and independent of any circuit voltages and currents, including the supply voltage to the op amp. The constant of proportionality between V_{R3} and T is defined above as G.

The reference voltage output is equal to the base-emitter voltage of Q_2 plus the voltage across R_3 (V_{R3}), so we can write:

$$V_{Ref} = V_{BE2} + V_{R3} = V_{BE2} + GT$$

Thus the reference output voltage is equal to a transistor V_{BE}, which has a negative temperature coefficient plus a voltage which increases in proportion to temperature (positive coefficient). If the value of G is set correctly, the variation in the GT voltage will cancel out the temperature coefficient of V_{BE2} and hence V_{REF} will not change with temperature.

As indicated by the equation given earlier, this is a matter of the correct choice of the three resistor values and the I_{S1}/I_{S2} ratio, which depends on the fabrication of the transistors.

The output of the circuit is thus a constant voltage that is independent of temperature. The output voltage is equal to the V_{BE} voltage of a transistor at absolute zero temperature ($T = 0$K), which is about 1.26V.

Other factors

The circuit in Fig.7 does not actually provide a zero temperature coefficient. A number of factors were not taken into account in the preceding discussion; a key one is the nonlinearity of the variation of V_{BE} with temperature (it was assumed to be linear). Other factors include component tolerances, resistor temperature coefficients and op amp offset. More sophisticated designs can improve on the performance of the circuit in Fig.7, which also leaves out specific details of implementation, such as how the current-density ratio of the two transistors is obtained (eg, by using multi-emitter transistors).

Bandgap-based reference ICs are available in both two-terminal and three-terminal forms and there is a large number of devices in the market. They are useful for situations where low reference voltages are requires, because low voltage Zener diodes tend to have poor performance. They also tend to be usable at lower currents than Zener references, making them more suitable for low power designs; however, the lowest current references tend to be noisier.

Examples

As an example, the AD1580 from Analogue Devices (**analog.com**) is a 1.225V two-terminal bandgap reference – you wire it up just like a Zener with a resistor selected to set the required operating current, which can be anything from 50µA to 10mA. The initial accuracy: ±0.1% maximum is better than the high precision Zener-based devices such as the LM399 (2%). However, the drift is 50ppm/°C – significantly worse than the LM399. They cost below £2.

As with Zener-based references, bandgap-based references are also available in three-terminal versions, which, as with Zener-based devices, tend to be available in round number and 'power of two' voltages and are able to provide more output current. An example, again from Analogue Devices, is the ADR4520 to ADR4550 series of ultra-low noise, high accuracy voltage references that is available in voltages from 2.048V to 5.0V. These have 2ppm/°C temperature coefficient (much better than the AD1580) and very good 0.02% initial accuracy. Price is around £4 to £5.

In this article we have looked at Zener and bandgap-based references, as these are probably the most well known approaches. However, they are not the only techniques available. We have mentioned a few example devices, but this only touches the surface of the large number of parts available. The LM399 and LTZ1000 tend to stand out because of their very high precision – and we note again that making full use of this is not necessarily easy. The devices mentioned should not be taken as particular recommendations – designers should investigate what is available in more depth before making a selection.

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AUDIO OUT

By Jake Rothman

Speaking volumes – Part 5

Active volume control – section 2

Last month, I described the rarer version of the Baxandall volume control circuit. This can be improved by isolating the pot from DC by adding coupling caps, as shown in Fig.13. This is necessary because all audio circuits containing potentiometers are susceptible to rotational noise unless expensive low-bias-current op amps are accompanied with servos to control the output off-set voltages. This has the potential to reduce wiper currents to picoamps (1pA = 10^{-12}A). However, using the industry-standard 5532 op amp and other bipolar input op amps, the input bias currents and output offsets are high, so blocking capacitors are essential. At this stage we should also ensure there are no unexpected low frequency roll-offs at both extremes and the middle of the pot rotation.

Capacitor distortion reduction measures can be added if desired. Since negative feedback across capacitors can cause low frequency response humps it's a good idea to check well below 20Hz with the signal generator, since they often lurk at frequencies as low as 4Hz. Fig.14 shows the circuit with capacitor distortion reduction measures incorporated if you wish to use non-wet capacitors such as tantalum or polymer varieties. Wet electrolytics can dry up and often have high leakage after prolonged periods of disuse.

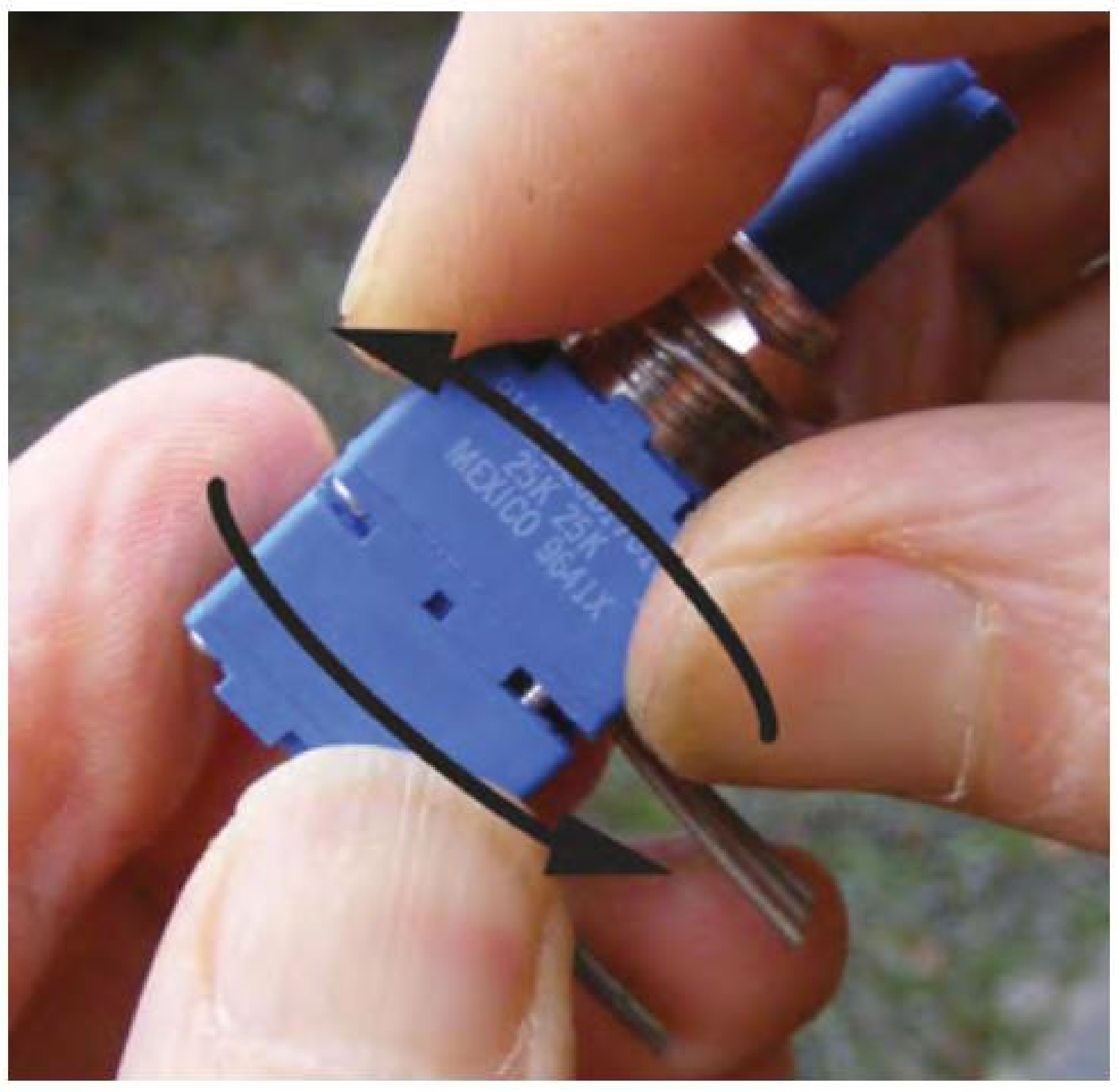

Fig.15. It can be seen that some dual-gang pots, such as this Bourns 91 series, are just two single sections riveted together. If the tracks don't start up at exactly the same time (as the volume is increased from zero) they can be twisted relative to each other until they do.

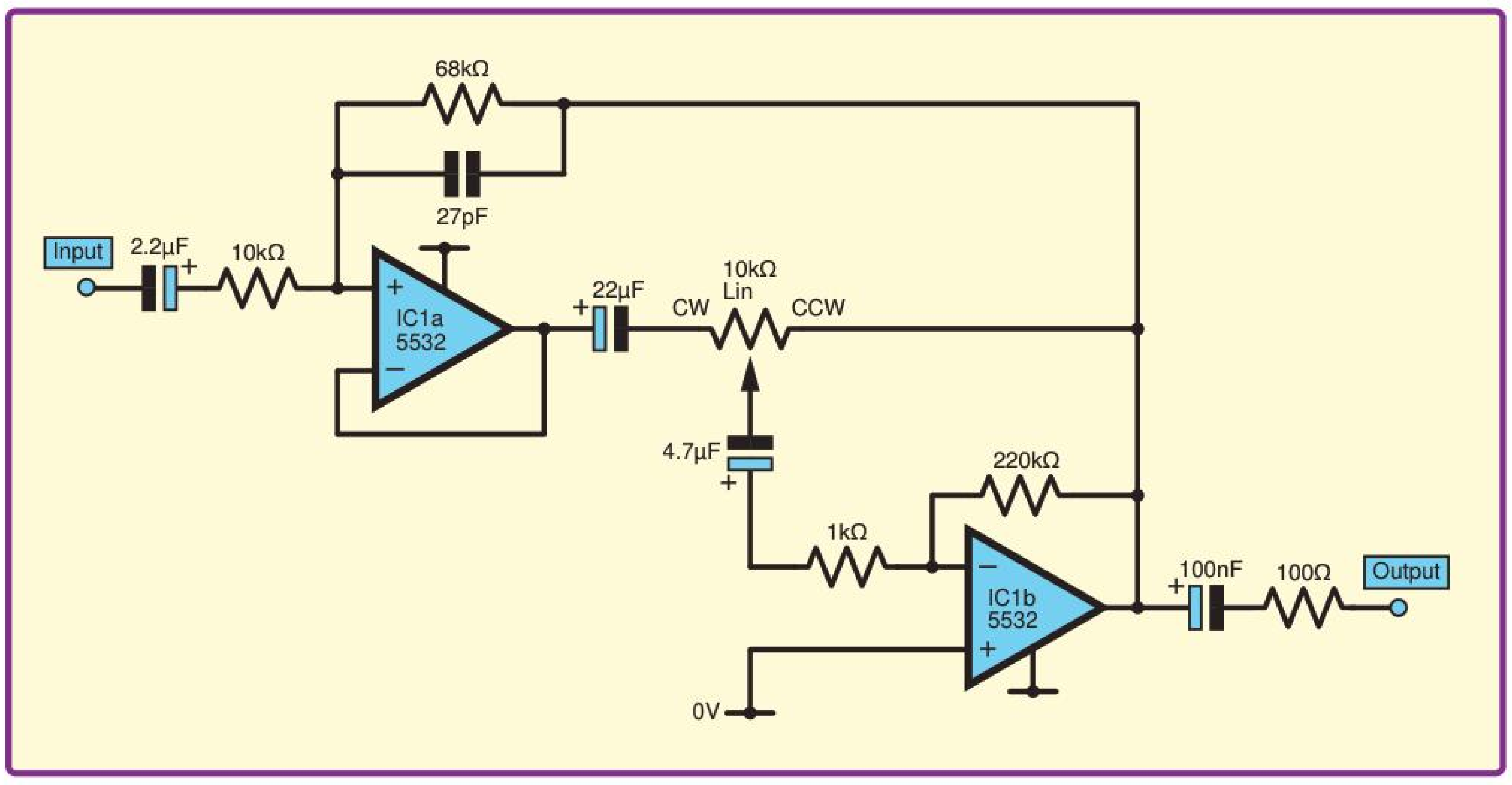

Fig.13. Adding coupling capacitors to avoid pot scratching.

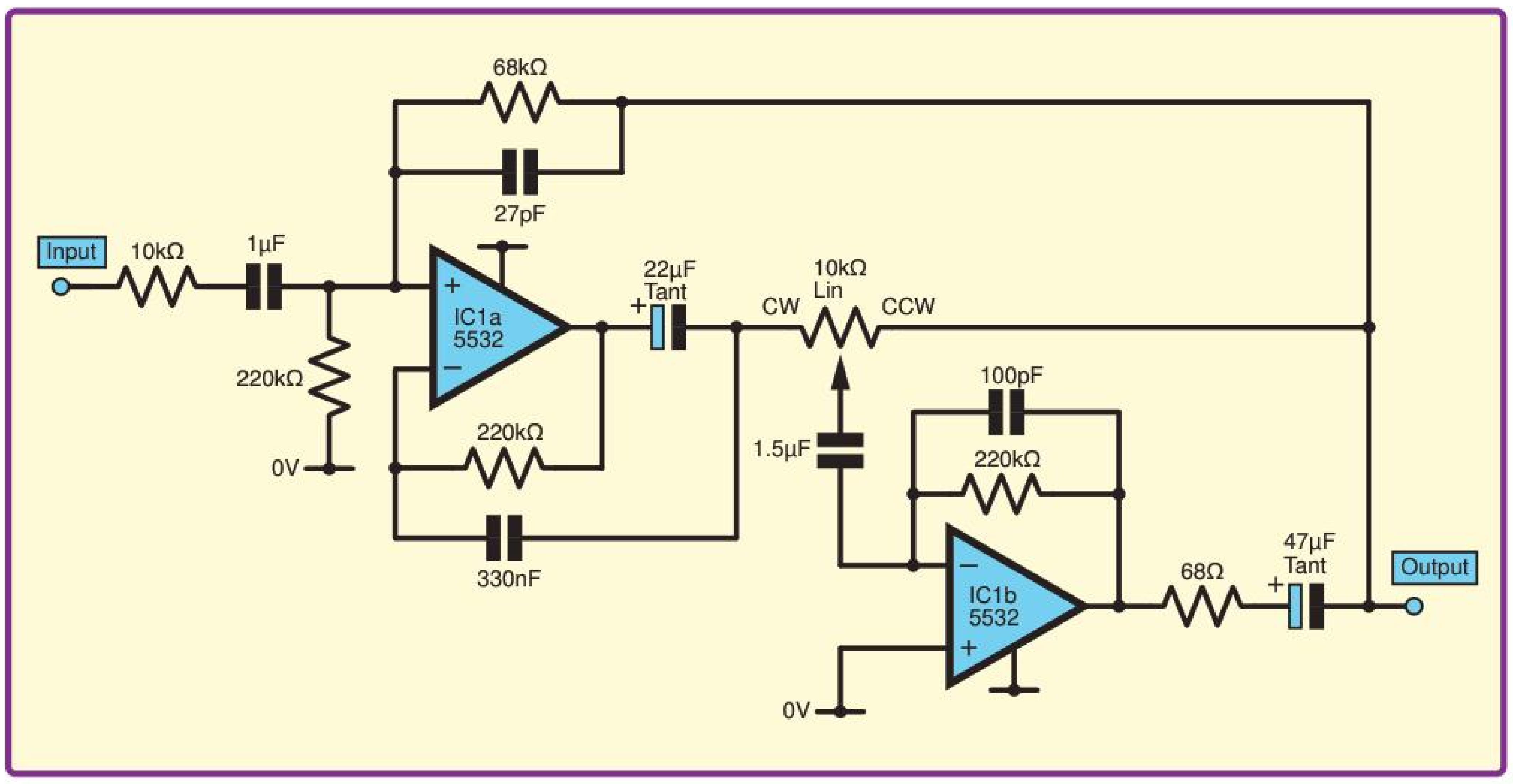

Fig.14. Putting capacitors in feedback loops to reduce distortion from solid types. Output resistance is also eliminated.

Volume tracking adjustment

One of the weaknesses of the Baxandall volume control circuit, like most linear-to-logarithmic potentiometer converting circuits, is sensitivity to the mechanical alignment of the two tracks at the lowest volume end. The resistive tracks must start at the same position as the control is turned up. This is because the gain change vs rotation curve is very steep initially – see Fig.11 last month.

Also, there must be no sudden jump in resistance as the track starts. 'Jump-on' resistance is much worse with some pots, such as those by BI Technologies, than others, which is why it's hardly ever on the data sheet. The Bourns 51 and 91 series pots are very good in this regard, but are poor with respect to track position alignment. This problem is easily fixed however, by twisting the two gangs of the pot relative to each other with a signal applied, until the tracks come up exactly together from zero (Fig.15 and 16). The assembly is then locked by melting the two halves together with a soldering iron (see Fig.24)

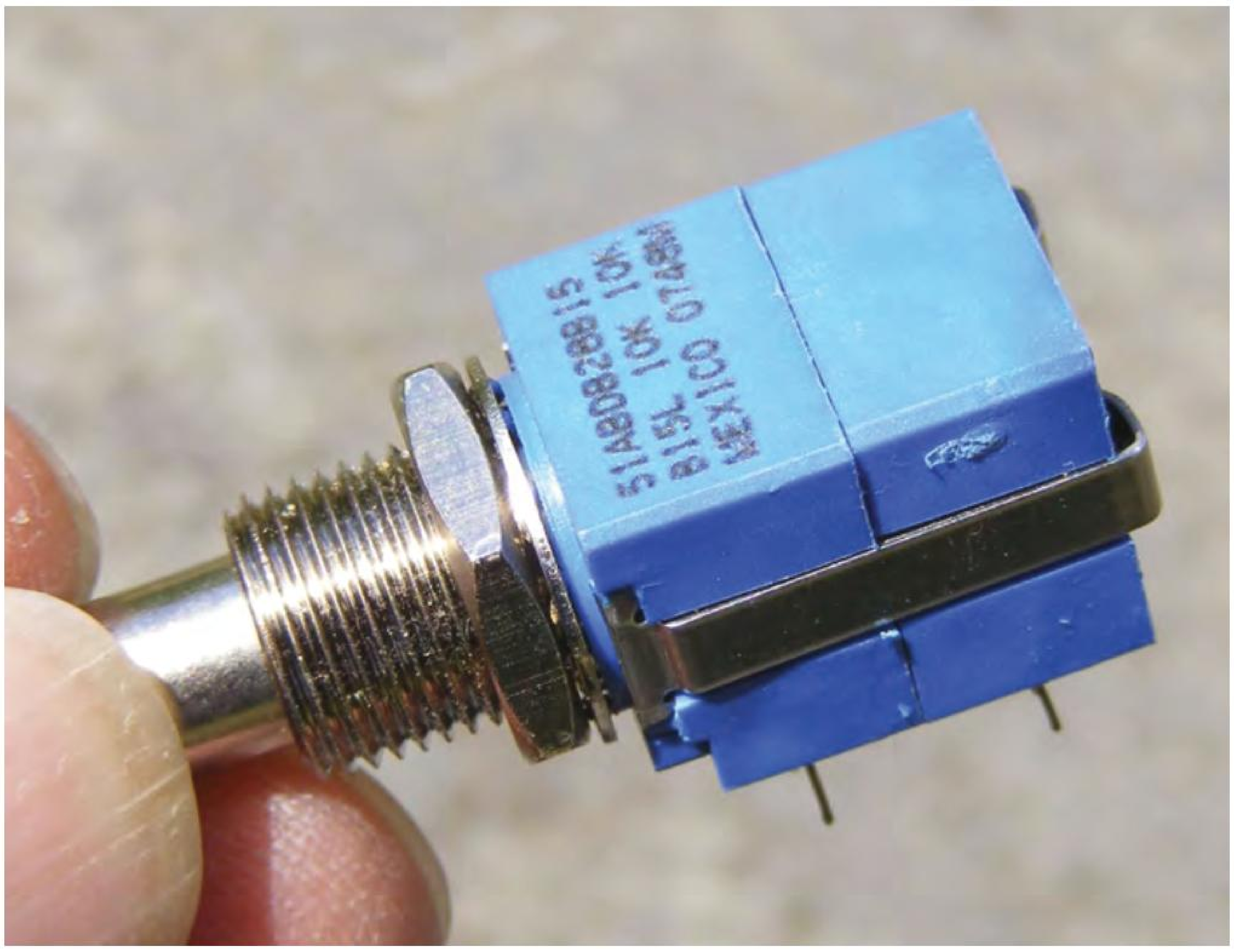

Fig.16. Once in alignment, the pot sections can be rigidly joined together with judicious use of the soldering iron or glue. Photo above shows slight rotational offset between the two sections prior to fixing. (See soldering iron marks on pot, lefthand side of Fig.24.)

then gluing with EVO-STIK. We now have a volume control system that tracks as almost as well as a Penny and Giles studio fader, but at much lower cost. The mechanical lifetime will be a 100,000 cycles rather than a million, but with normal domestic use it should still last 20-30 years.

Gain

Another problem with Baxandall volume circuits is they have a gain that is typically in the range of 6 to 10 (+16dB to 20dB) which means dedicated low sensitivity power amps have to be used. The gain can't be reduced, since it is this pick up in gain towards the end of the track rotation that gives the log action. Thus, a CD player giving the full output of 2V peak-to-peak could result in an output of over $12V_{pk\text{-}pk}$ with the volume control fully up. One way round this could be to use a step-down balancing transformers, as in Fig.17. A great advantage of using transformer input balancing is that it can eliminate the dreadful power supply and digital switching noise that some computers suffer from by isolating the computer ground from the pre-amp signal ground. Some mini PCs with external PSUs are very bad in this respect; it's even possible to hear disk drive motor interference.

Another way to reduce gain would be to put a passive tone control in front (shown in Fig.18) which has around 15dB attenuation, but this will worsen the noise. An interesting alternative is to make the power amp itself part of the volume control stage. This can create difficulties with the high frequency compensation arrangements since the power amp stage may have to be stable down to zero gain. We'll discuss an integrated amplifier design with this technique in the future.

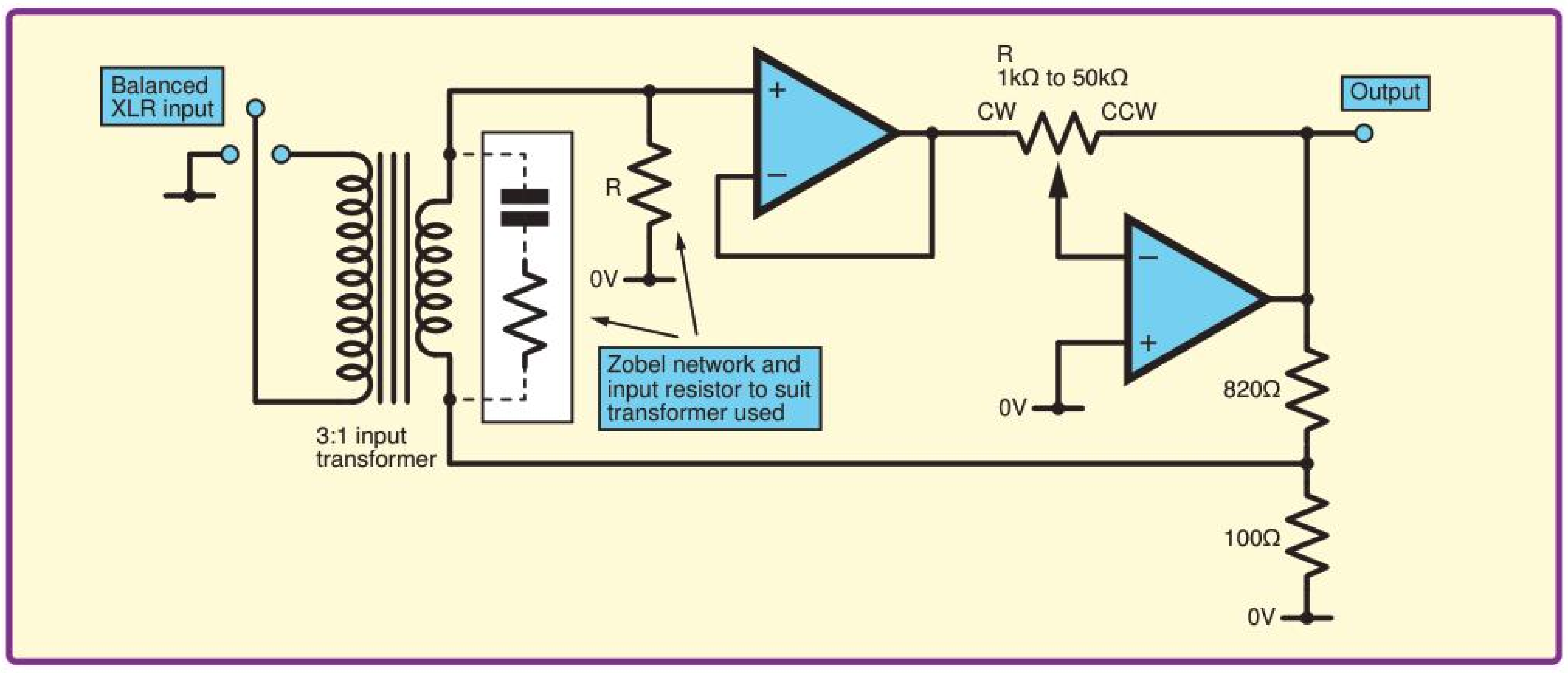

Fig.17. The floating input version variant of Baxandall's circuit. This can be used with an input transformer to reduce the maximum gain. (I've still got to test this – are there any readers who want to try it?).

Converting op amp designs to discrete single rail

Op amp circuits normally need dual voltage rails, which can be inconvenient if you want to use 'wall-wart' or bought-in power supplies. Now that we have a fully functioning op amp circuit (shown in Fig.13) we can convert it to the single-rail design shown in Fig.19. The outputs of the op amps must all be biased up to half rail using a decoupled potential divider consisting of equal value resistors. This half-rail bias voltage is connected to what is normally the 0V reference point. The pin 4 negative supply pins then have to be connected to what is now the new ground rail. It is also essential to correctly orient the capacitors, since they now have DC across them.

Using this approach it's easier to convert to a discrete design, which is usually single rail. I call this engineering process of reversing history 'retr-audio', and the market likes it. You need to be much more careful with earthing on single-rail circuits because the power supply current return and signal earth are combined. The following are the discrete circuit blocks (the buffer and inverting amplifier) that can be used to replace op amps, giving at least a 3dB headroom improvement with a standard 48V supply.

Discrete buffer

Let's start with a discrete buffer stage. There are several techniques available, with increasing complexity and performance, as shown in Fig.20a to 20e. The simplest is to use an emitter follower with a resistor as a load, as in Fig.20a. The resistor can then be replaced with a constant current sink, shown in Fig.20b, such as a current regulator diode (CRD) which improves the load driving ability on negative cycles. Alternatively, we could use a JFET current sink running at its I_{dss}, as shown in Fig.20c, or a bipolar transistor current sink (that needs a voltage reference) as shown in Fig.20d. The voltage reference can be replaced by a simple voltage divider if a regulated power supply is used, as shown in Fig.20e.

Supply current and consequent dissipation can be almost halved by modulating the current source, giving a form of push-pull operation. This further improves linearity for a given load and power consumption. It is always good engineering practice to reduce unnecessary power consumption, even if it means just saving a few hundred milliwatts from a pre-amp.

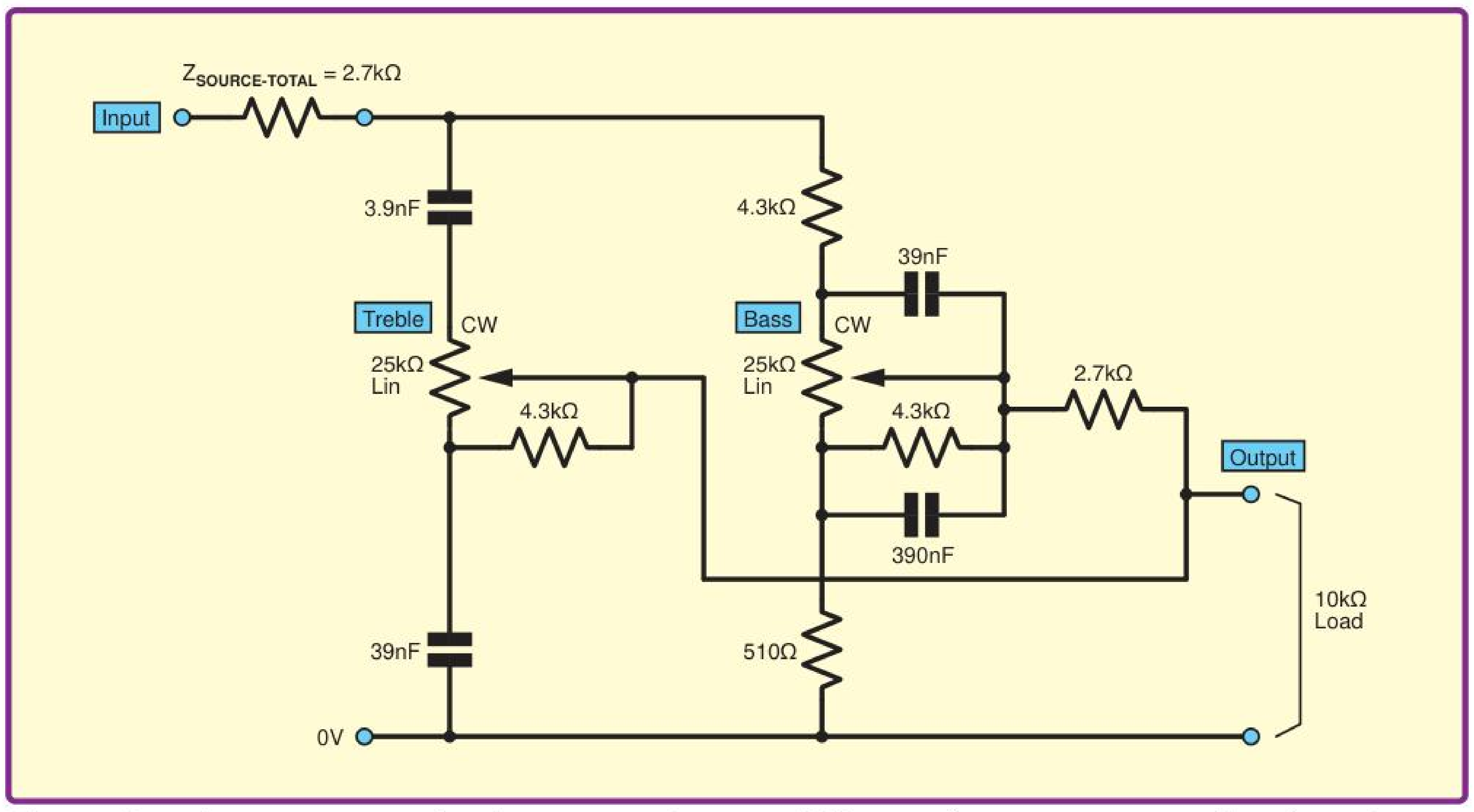
$Z_{SOURCE-TOTAL}$ = 2.7kΩ
Input
3.9nF
Treble
CW
25kΩ Lin
4.3kΩ
39nF
0V
4.3kΩ
39nF
Bass
CW
25kΩ Lin
4.3kΩ
390nF
510Ω
2.7kΩ
Output
10kΩ Load

Fig.18. Passive tone control – its attenuation could be used to compensate for the gain produced by the Baxandall volume control; it may need a buffer. Note that normally logarithmic pots are used here, but in this design I have used loaded linear pots.

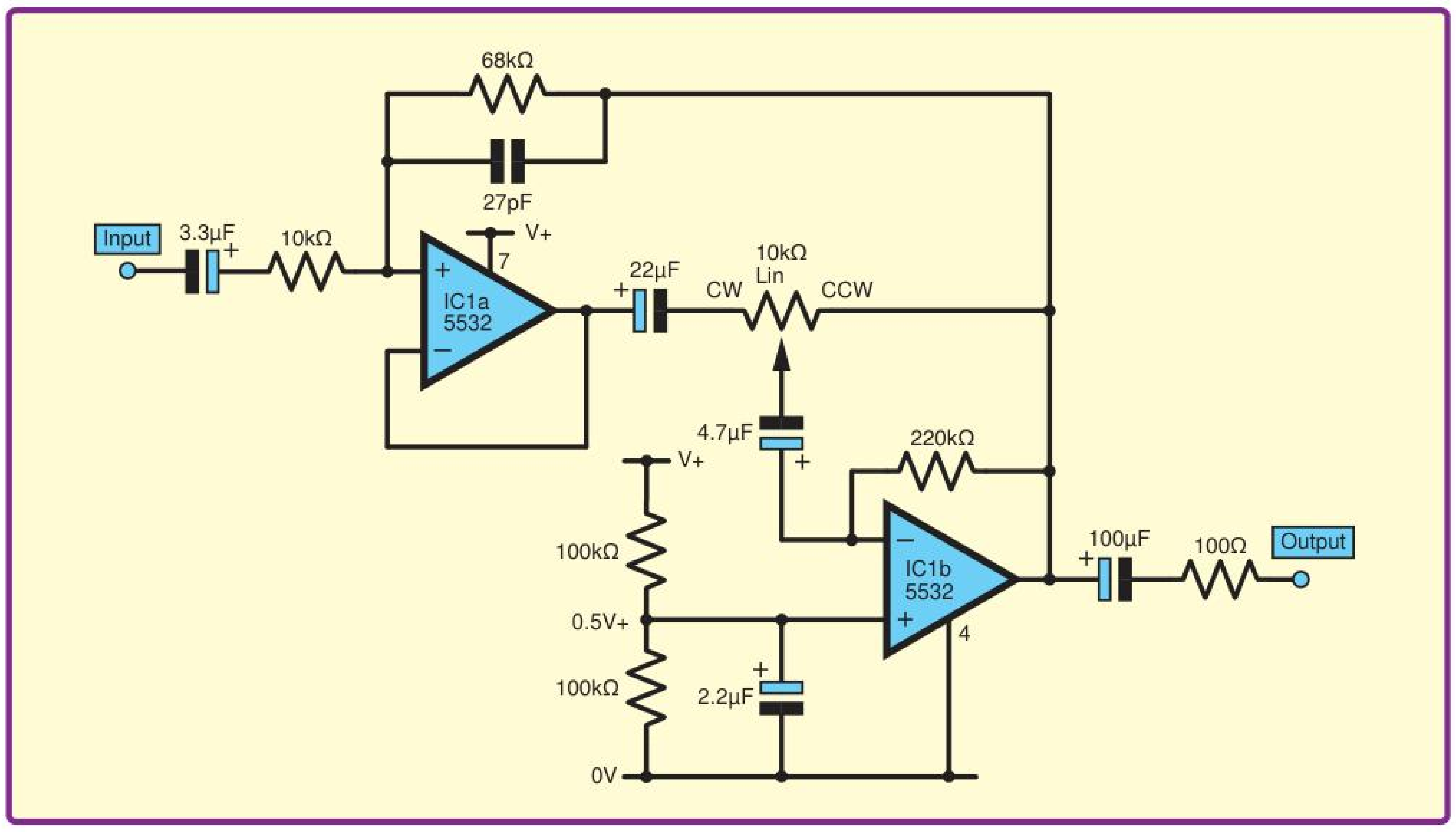
68kΩ
27pF
Input
3.3µF
10kΩ
V+
7
IC1a
5532
22µF
10kΩ Lin
CW
CCW
4.7µF
V+
220kΩ
100kΩ
0.5V+
100kΩ
2.2µF
0V
IC1b
5532
4
100µF
100Ω
Output

Fig.19. Single-rail version of the Baxandall volume control (see Fig.12).

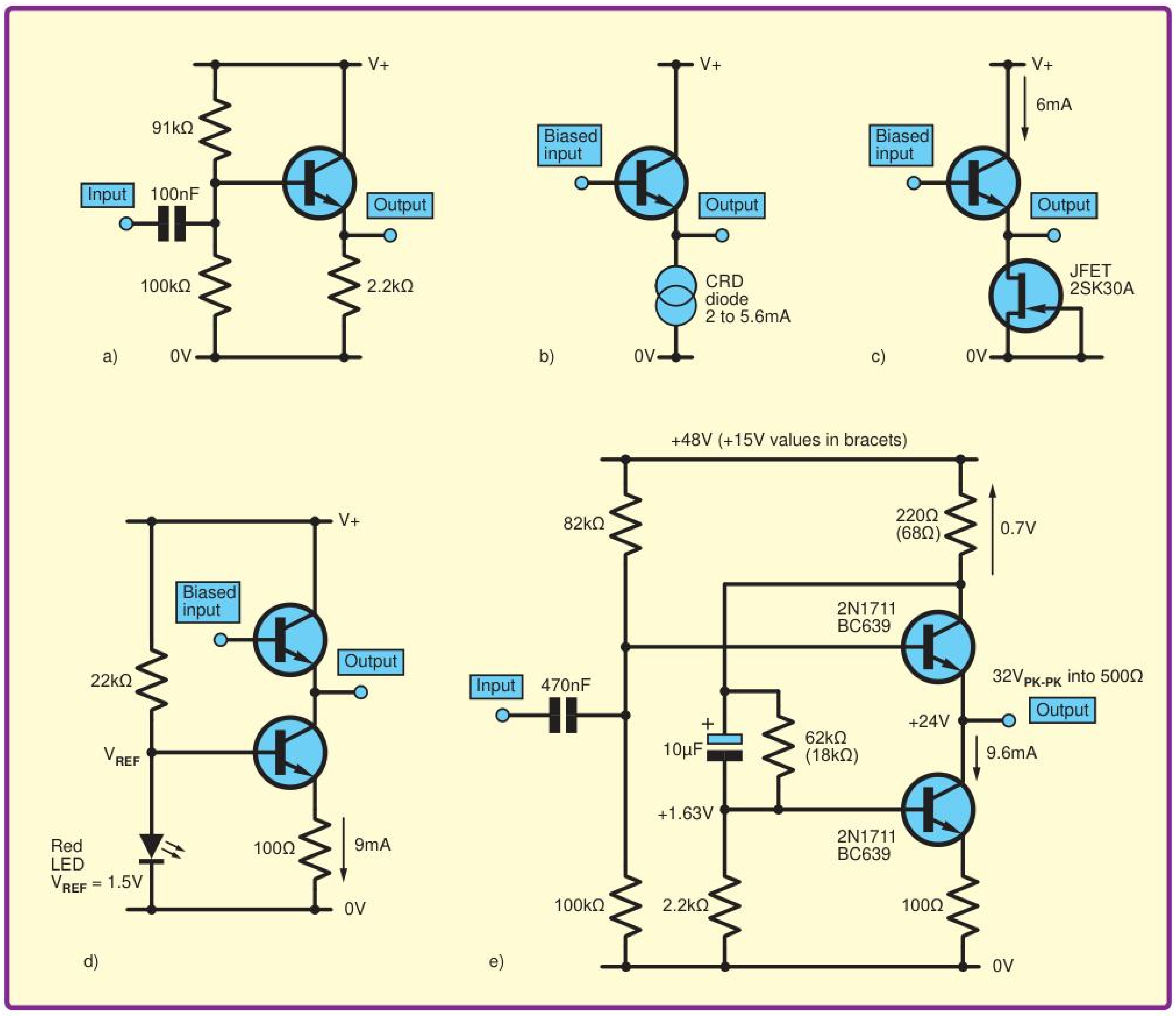
V+
91kΩ
Input
100nF
Output
100kΩ
2.2kΩ
a)
0V
V+
Biased input
Output
CRD diode 2 to 5.6mA
b)
0V
V+
6mA
Biased input
Output
JFET 2SK30A
c)
0V
V+
Biased input
Output
22kΩ
V_{REF}
Red LED
V_{REF} = 1.5V
100Ω
9mA
0V
d)
+48V (+15V values in bracets)
82kΩ
220Ω (68Ω)
0.7V
2N1711 BC639
Input
470nF
32V_{PK-PK} into 500Ω
+24V
Output
10µF
62kΩ (18kΩ)
9.6mA
+1.63V
2N1711 BC639
100kΩ
2.2kΩ
100Ω
0V
e)

Fig.20. Discrete buffer circuits: a) simplest resistive load emitter-follower version; b) current sink increases output on negative-going cycles; c) JFET used as a current sink; d) bipolar transistor used as a current sink; e) modulated bipolar current sink follower stage. This circuit needs a regulated 48V supply.

It is essential with battery-operated equipment, and some obsessive audiophiles operate their preamps from batteries to minimise noise.

I first saw this technique in the Nelson-Jones scope probe in *Wireless World* (August 1968, p.276). This was subsequently used by Douglas Self in the RIAA section of his 1979 pre-amp. This modulation technique was also done in the valve era and was called the 'White follower'. This signal is derived from a resistor in the power line to the follower stage.

Since bipolar transistors have a fairly low input impedance, it is necessary to use an electrolytic capacitor for coupling the modulation signal to the current sink to maintain the effect to low frequencies. It is desirable to eliminate electrolytic capacitors in long-life equipment. One way is to use a common-base stage as a coupling element, acting as an amplifier and DC level translator, eliminating the need for a capacitor. This technique allows full gain to DC and a reduced sense resistor value – see Fig.21. Nelson-Jones also mentioned this technique, but rejected it because high-voltage silicon PNP transistors were expensive at the time. The power supply rejection ratio (PSRR) of the capacitor-coupled modulated current sink is poor because the capacitor injects supply noise. If a regulated power supply is used then this shortcoming is not a problem. The transistor coupling in Fig.21 has excellent PSRR because it has a fixed base-emitter reference voltage. The system also has excellent current stability with changes in supply voltage. These qualities make it an excellent topology for small class-A power amplifiers. In *Wireless World* (June 1973) PL Taylor described a 20W class-AB design. John Broskie took the idea further with MOSFETs for his headphone amp at **tubecad.com**.

Going back to the FET current sink in Fig.20c, a simpler method is to use a JFET as in Fig.22. Its high input impedance allows a non-polarised capacitor to be used and its inherent constant-current characteristic means a voltage reference is not required. The catch is the larger spread in the current value between devices and the relatively low drain-source voltage (V_{ds}) ratings of most available JFETs (since the amplifier is running on a +48V rail). FETs that could be used, include the 50V 2SK30A, 2SK209BL

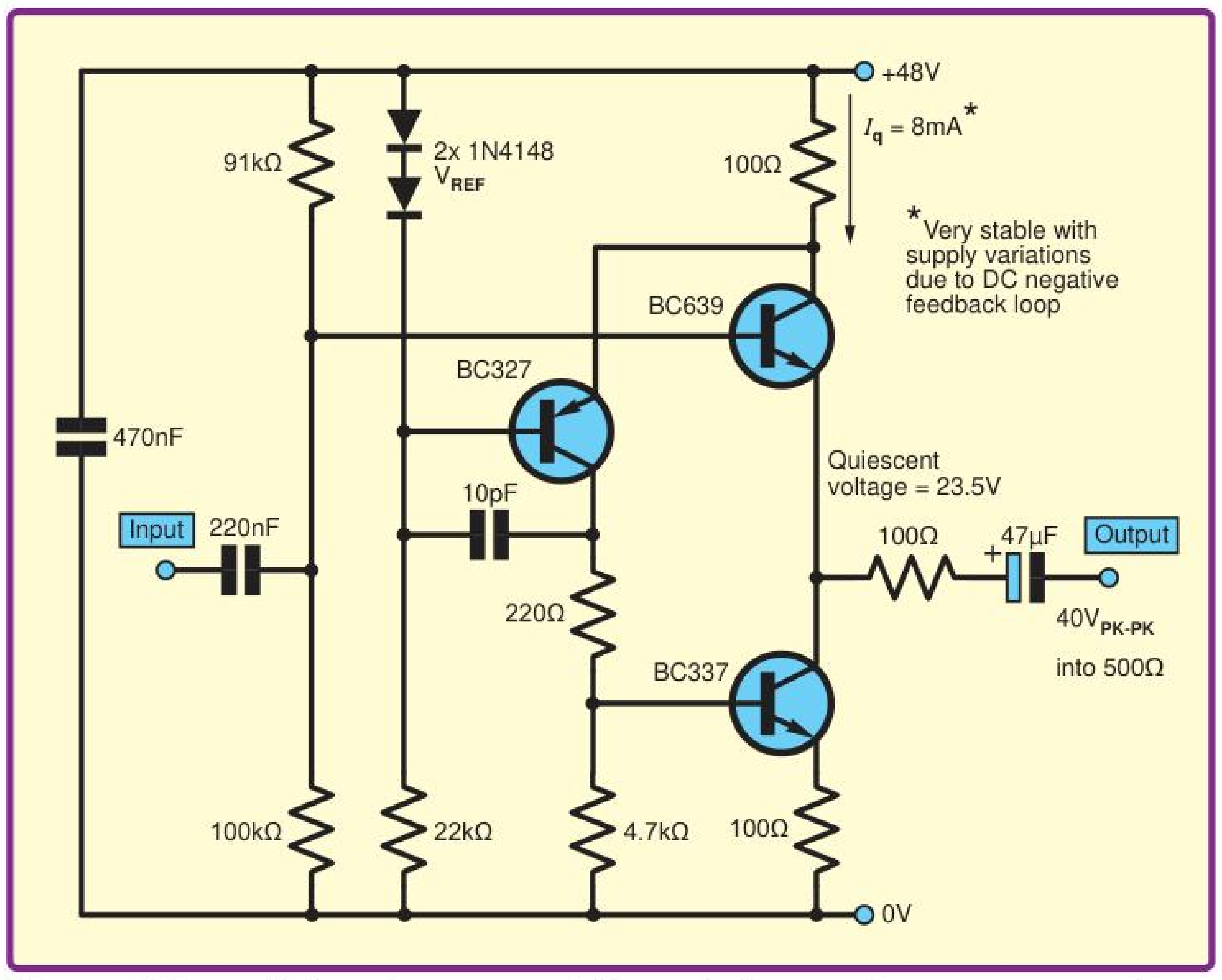
+48V
91kΩ
2x 1N4148
V$_{REF}$
100Ω
I_q = 8mA*
*Very stable with supply variations due to DC negative feedback loop
BC639
BC327
470nF
Quiescent voltage = 23.5V
Input
220nF
10pF
100Ω
47µF
Output
220Ω
40V$_{PK-PK}$ into 500Ω
BC337
100kΩ
22kΩ
4.7kΩ
100Ω
0V

Fig.21. 'Ring-of-three' current sink modulator using a common-base stage for coupling. This design is complex and possibly more prone to high frequency (HF) stability problems, but it's the best buffer I've come up with so far.

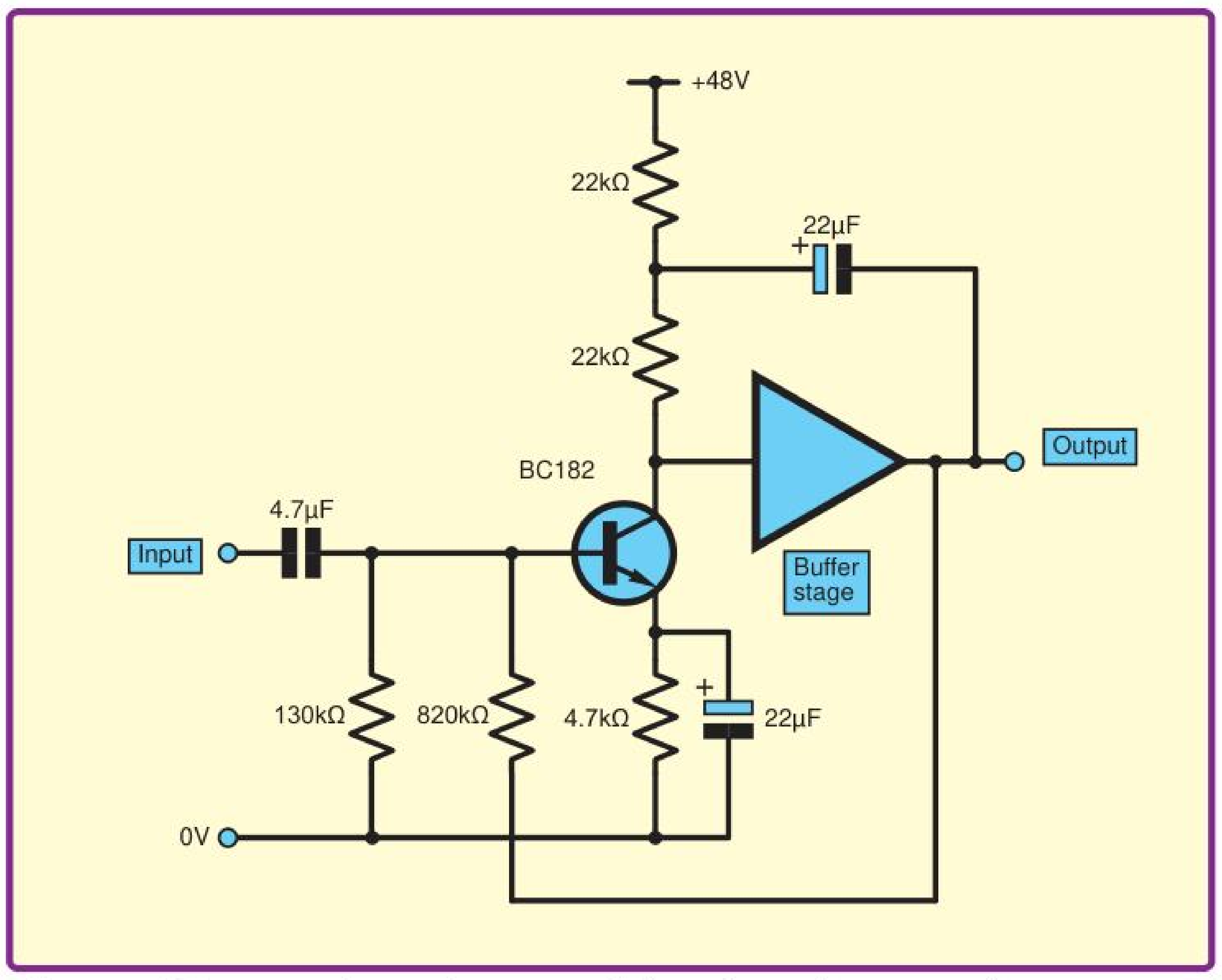
+48V
22kΩ
22µF
22kΩ
Output
BC182
4.7µF
Input
Buffer stage
130kΩ
820kΩ
4.7kΩ
22µF
0V

Fig.23. Discrete inverting amplifier based on a bootstrapped common-emitter stage. Note an output buffer is needed for its performance to approach that of an op-amp.

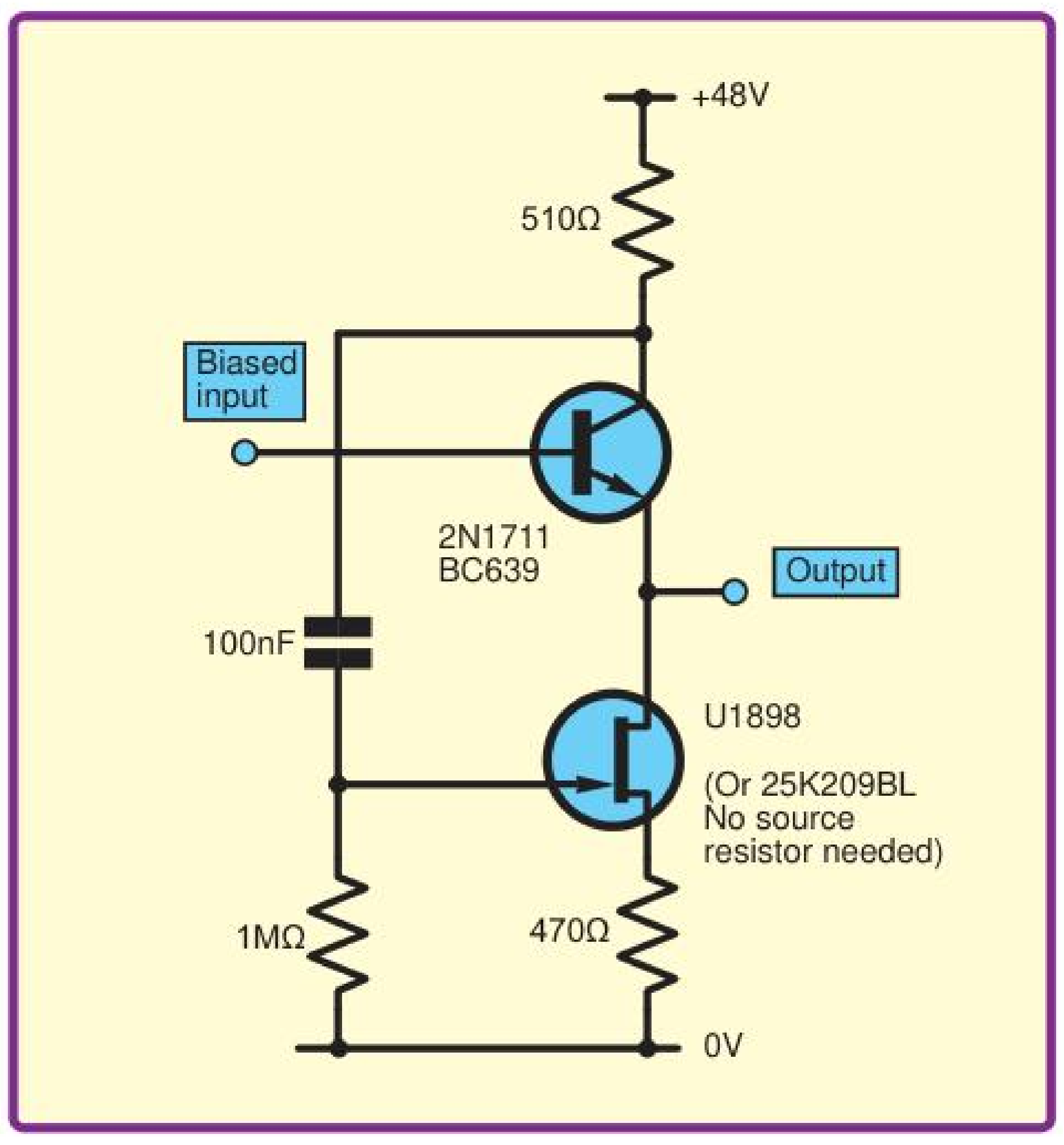
+48V
510Ω
Biased input
2N1711
BC639
Output
100nF
U1898
(Or 25K209BL No source resistor needed)
1MΩ
470Ω
0V

Fig.22. Modulating a JFET current sink avoids the need for an electrolytic capacitor.

and 2N4341. I also used the Fairchild U1898, which has a 40V voltage rating, but does appear reliable in this application. It has a high I_{dss} of around 56mA. This is reduced to a controlled 6.8mA with a 470Ω source resistor. The output stage can have a 220Ω source resistor giving a 12mA standing current, sufficient to drive some output transformers if needed. The follower transistor (TR4, Fig.25) should then be beefed up a bit, say to a BC639 or other 600mW type.

Testing

Testing high-voltage buffer circuits is problematic, since most signal generators can only output about 24V$_{pk\text{-}pk}$. I got around this by using a 1:3.6 ratio audio transformer (RS part 201-6374) to step this up to over 60V at 1kHz, sufficient to observe clipping behaviour.

Discrete inverting amplifier

The next stage is to convert to discrete form the inverting amplifier. A bootstrapped common-emitter stage is used, along with an output buffer. The topology for this circuit is shown in Fig.23. This inverting gain-block has an open-loop gain of 1500. Although much lower than an op amp, its good basic linearity and the low maximum

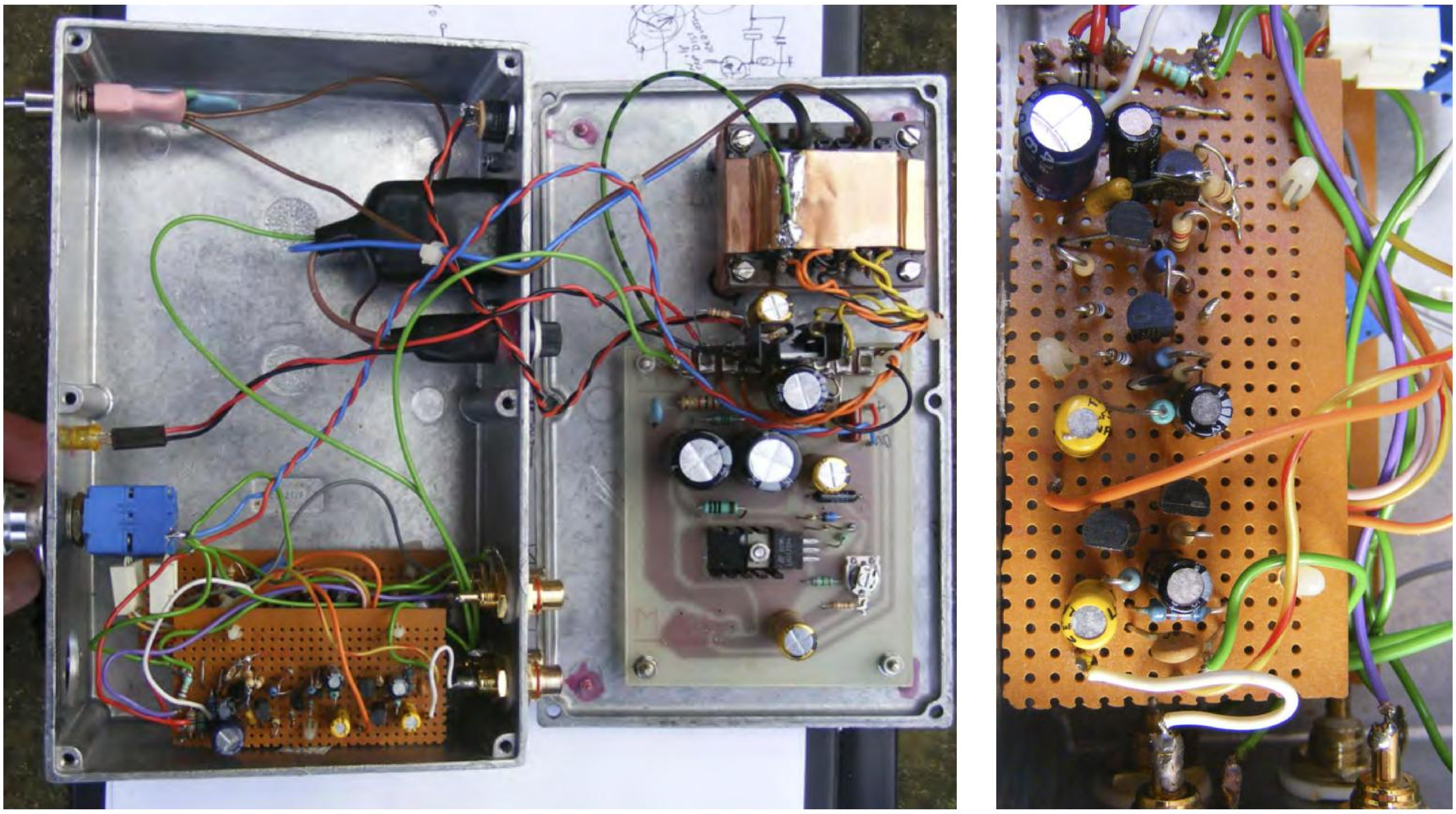

Fig.24. The active volume circuit built on stripboard, and inside the active volume control unit. I wish I had used a bigger box!

gain required means it still gives low distortion.

Discrete Baxandall volume system

Putting the two discrete blocks into the op amp topology worked out earlier in Fig.19, we get the complete circuit built on stripboard in Fig.24, and Fig.25 shows the complete circuit diagram. The input buffer does not have to handle the full signal level, so the current sink was left unmodulated. I left off the tantalum capacitor distortion reduction circuitry and used bipolar components that offer low distortion but have a shorter life.

Can I hear the difference with all this work compared to the good old 5532? To be honest, no! Can my studio engineer friends? Yes, some of them can. (I was a bit optimistic cramming it into the 7 × 4-inch box with an internal 48V power supply, plus a 5V supply for an external DAC.)

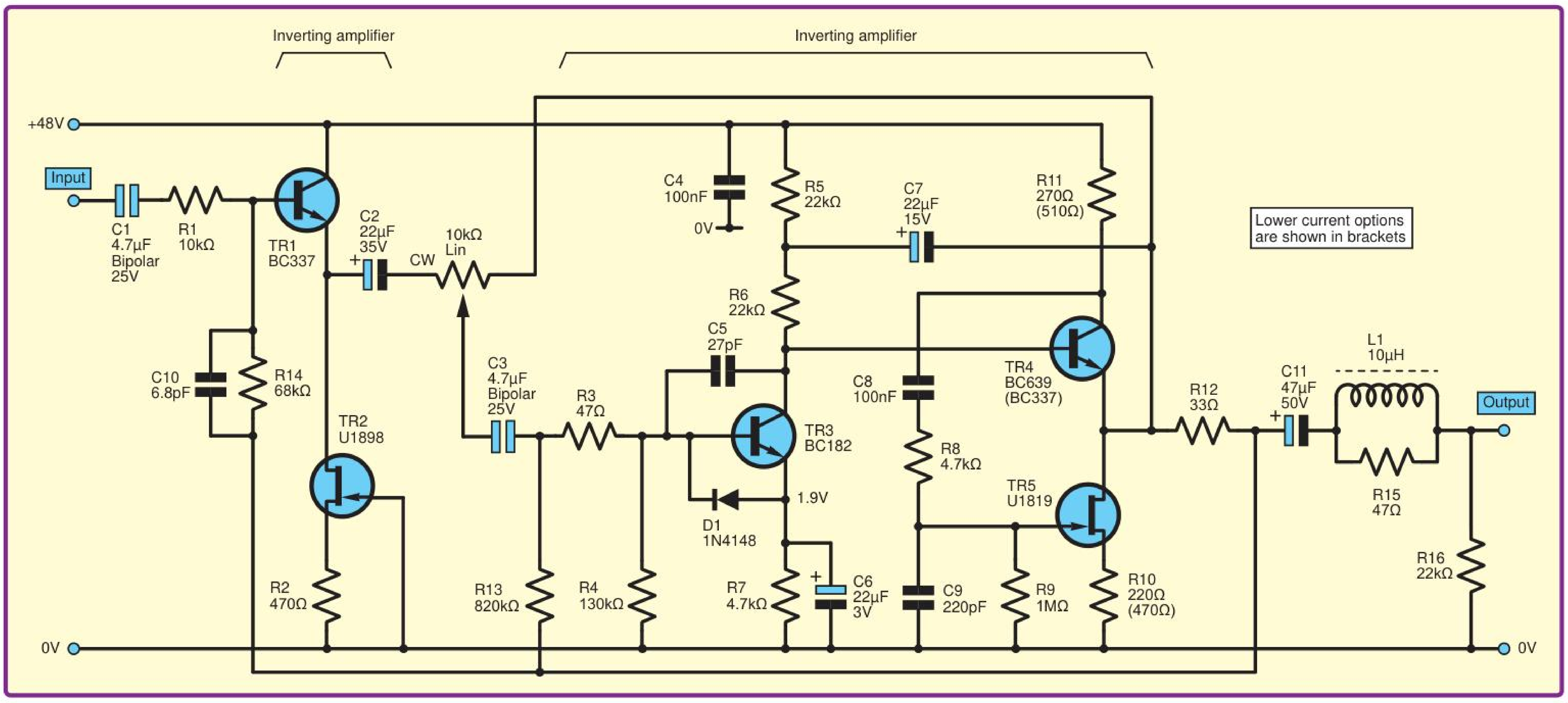

Fig.25. Combining an input buffer, potentiometer and buffered inverting-gain stage to form a Baxandall active volume circuit in discrete form. There are some small capacitors (C5, C9, C4), a gate resistor (R8) and an output inductor added to prevent high frequency oscillations.

HP 34401A Digital Multimeter 6 ½ Digit

HP 54600B Oscilloscope Analogue/Digital Dual Trace 100MHZ

MARCONI 2955B Radio Communications Test Set

FLUKE/PHILIPS PM3092 Oscilloscope 2+2 Channel 200MHZ Delay TB, Autoset etc

LAMBDA GENESYS	PSU GEN100-15 100V 15A Boxed As New	£325
LAMBDA GENESYS	PSU GEN50-30 50V 30A	£325
HP34401A	Digital Multimeter 6.5 digit	£275-£325
HP33120A	Function Generator 100 microHZ-15MHZ	£260-£300
HP53131A	Universal Counter 3GHZ Boxed unused	£500
HP53131A	Universal Counter 225MHZ	£350
HP54600B	Digital Oscilloscope 100MHZ 20MS/S	from £75
IFR 2025	Signal Generator 9kHz - 2.51GHZ Opt 04/11	£900
Marconi 2955B	Radio Communications Test Set	£800
R&S APN62	Syn Function Generator 1HZ-260KHZ	£195
Fluke/Philips PM3092	Oscilloscope 2+2 Channel 200MHZ Delay etc	£250
HP3325A	Synthesised Function Generator	£195
HP3561A	Dynamic Signal Analyser	£650
HP6032A	PSU 0-60V 0-50A 1000W	£750
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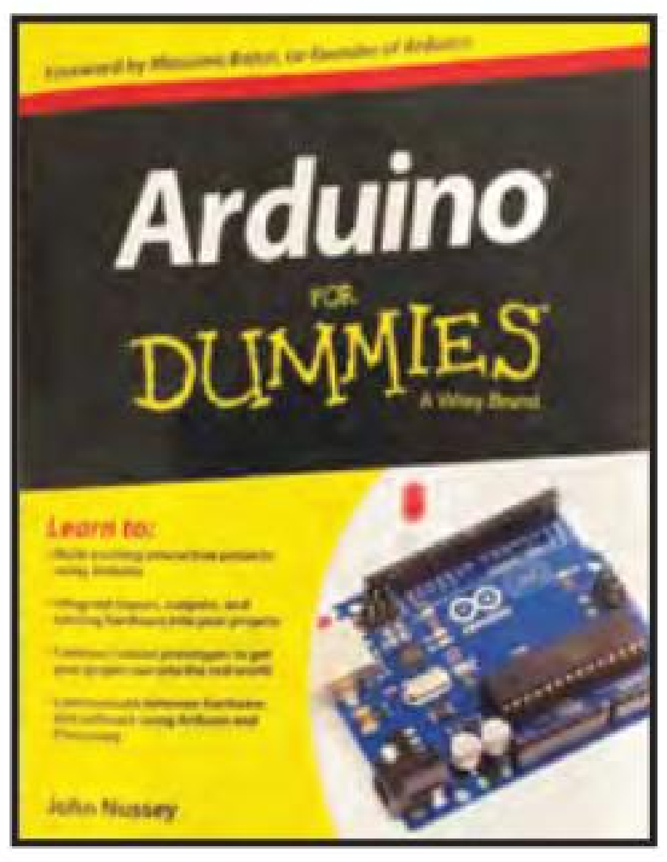

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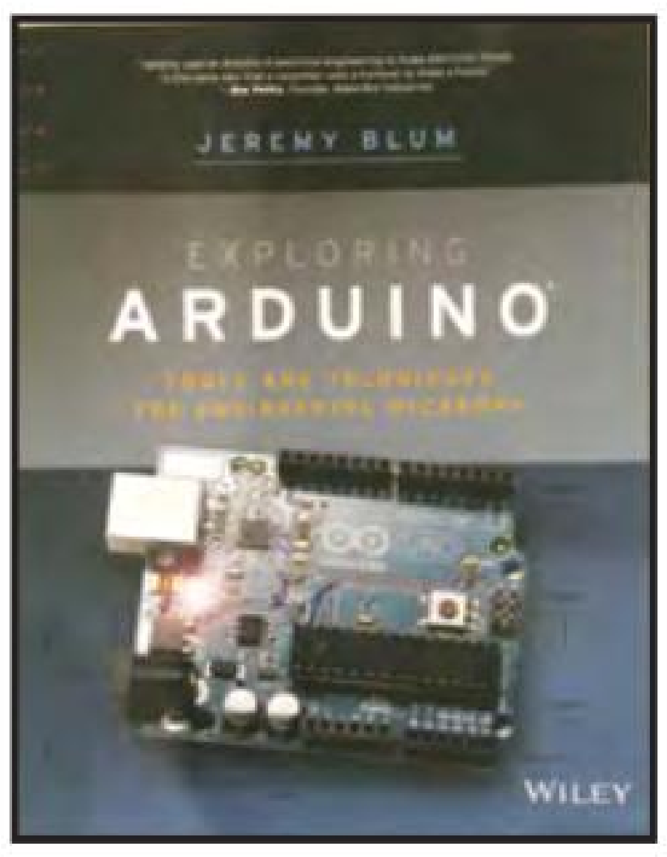

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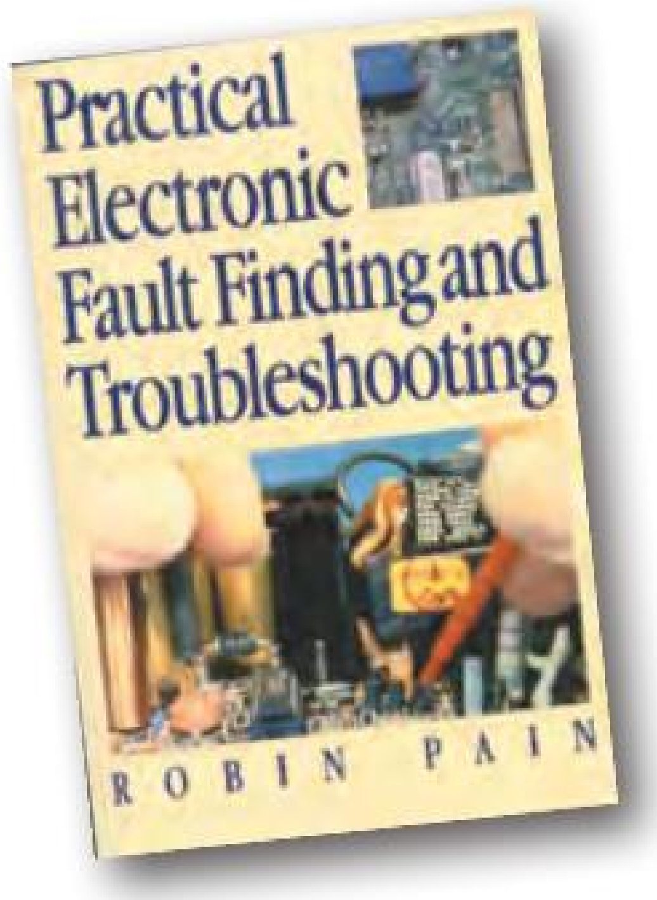

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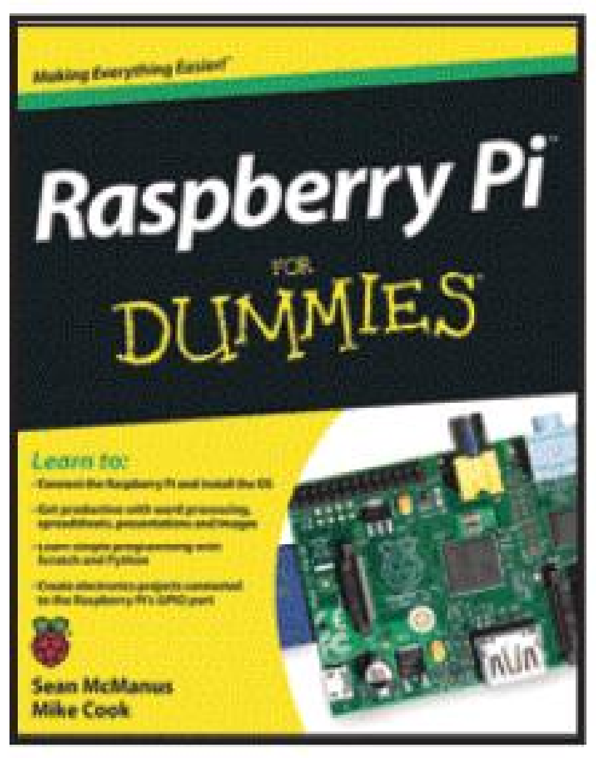

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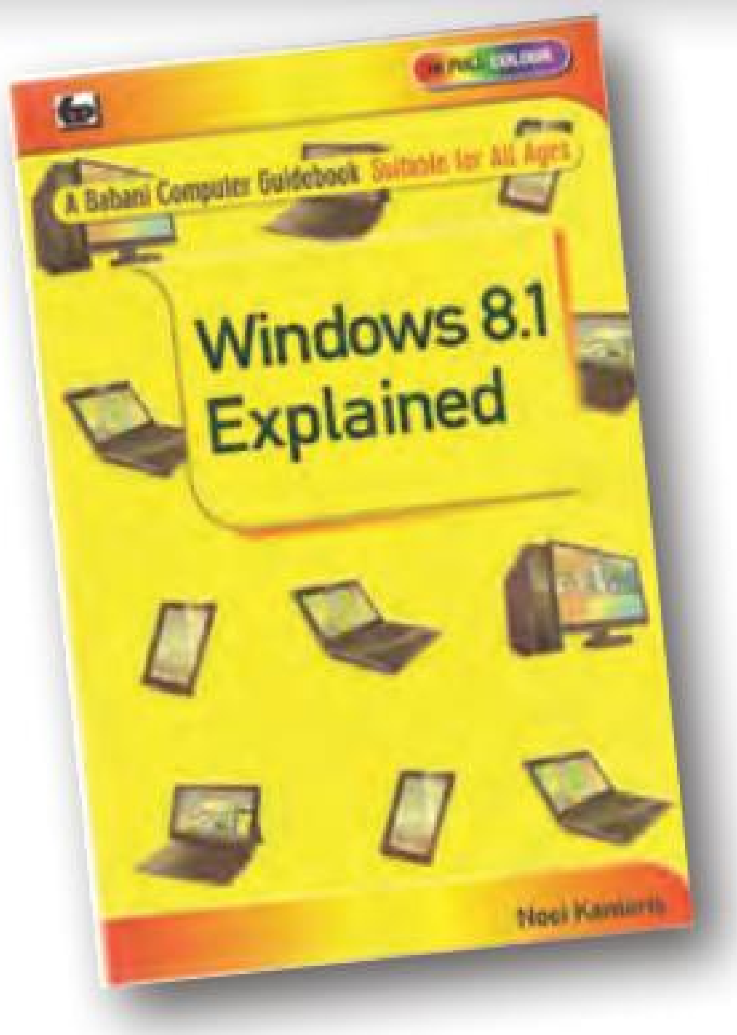

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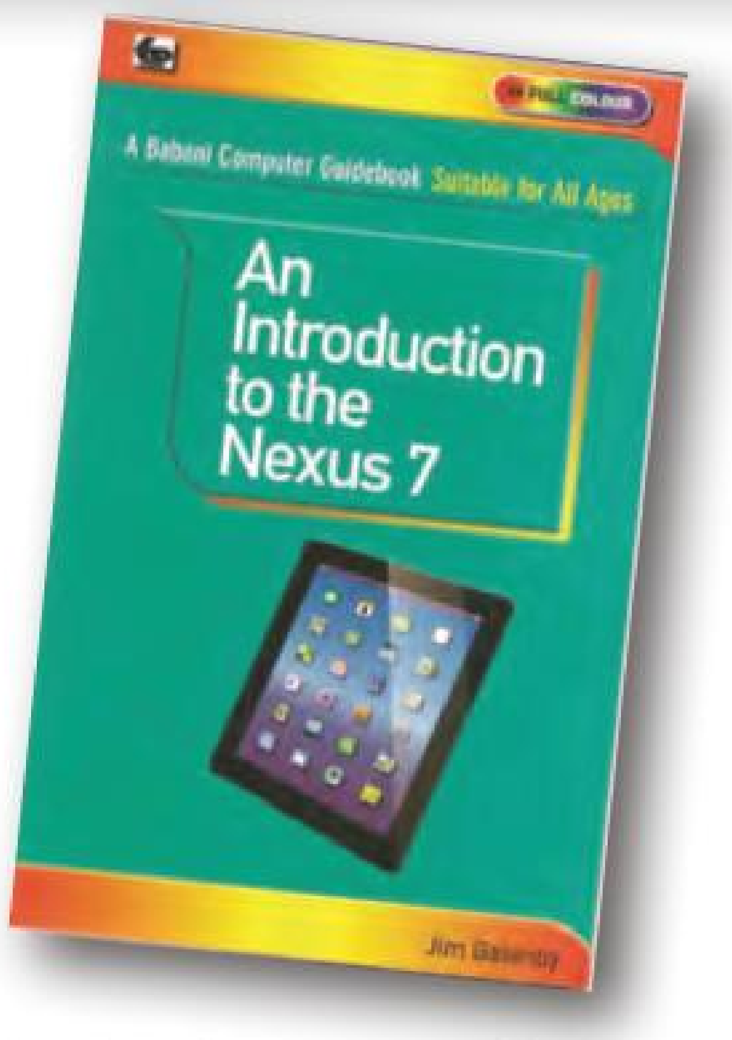
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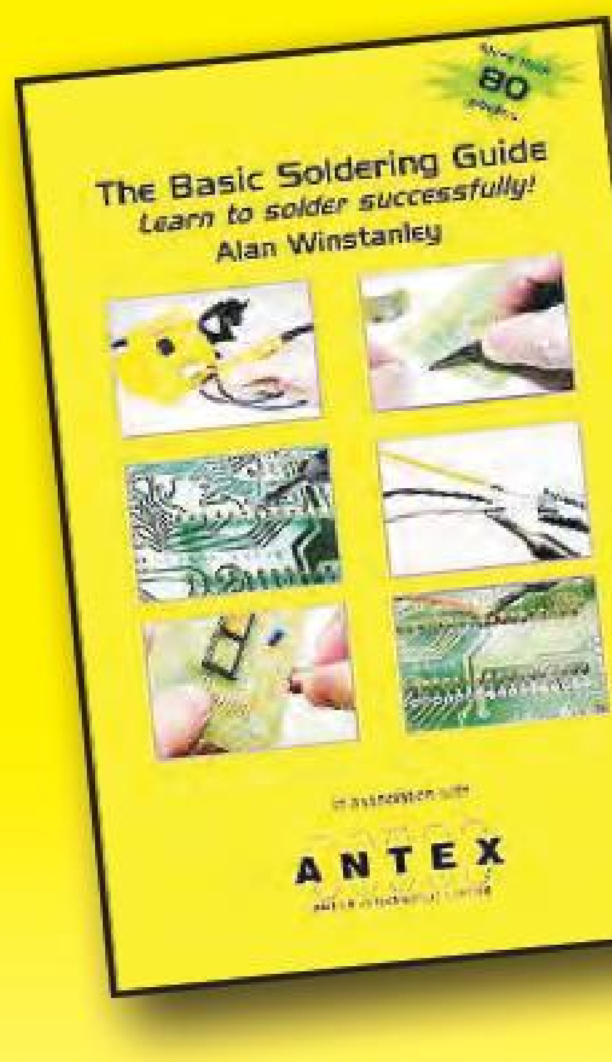

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Max's Hot Beans

By Max The Magnificent

Have you got the tubes?

I know, I know... you were expecting to read the third and final segment in my mini-series on coding tips and tricks for NeoPixel rings. Well, you are no more surprised than I, because that's the column I was planning on writing... right up until I ran across the most amazing Nixie tube clocks.

These little beauties are created by Paul Parry – the owner of Bad Dog Designs (**http://bit.ly/1VRJeOF**) – a man whose brass acorn nuts your humble narrator is not fit to polish. If you take a scroll through Paul's website, you will discover the most amazing collection of Steampunk Nixie tube clocks. I mean, we are talking about clock after clock after... you have no idea, but you'll see what I mean when you visit his site. For example, feast your orbs on Paul's Turing Clock (Fig.1). Wouldn't you like to have this little beauty gracing your home?

In fact, I was chatting with Paul on the phone earlier today. I was saying how, if I had created these masterpieces, I wouldn't be able to part with any of them. Paul responded that he has to sell them to make room for their successors. In fact, as strange as it may seem, the only Nixie tube clock Paul owns himself is a plastic kit his kids bought for him as a present years ago. It really is a funny old world when you come to think about it.

Initially, my heart was taken by Paul's Araminta Clock – see Fig.2. Obviously, it's the tubes that immediately grab your attention, but then your eyes are drawn to the other details, like the antique wooden box, the brass plates on the top and the front, the brass tubes snaking around, and the strange thingamabob sticking out of the left-hand side.

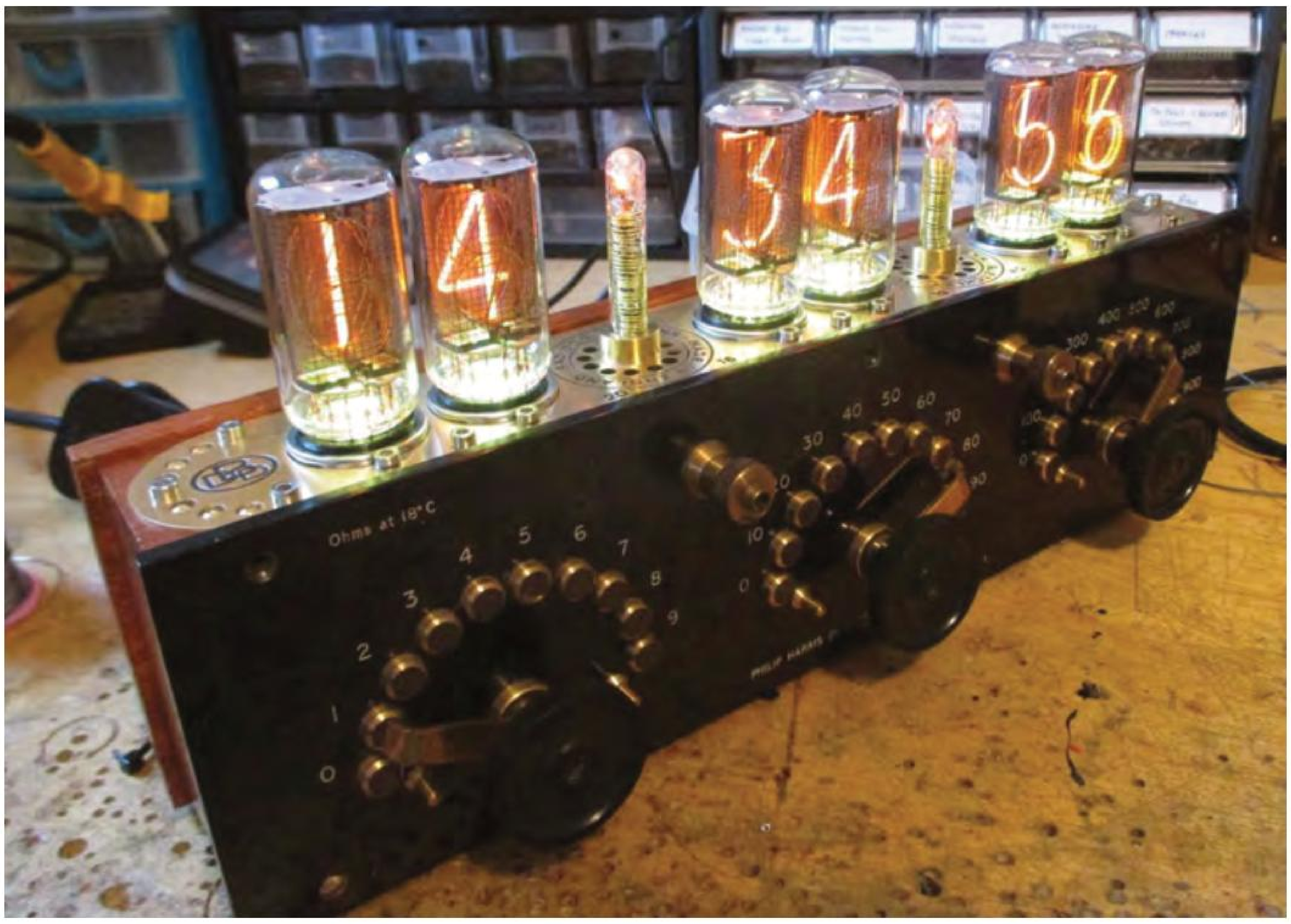

Fig.1. The Turing Clock (Source: Bad Dog Designs)

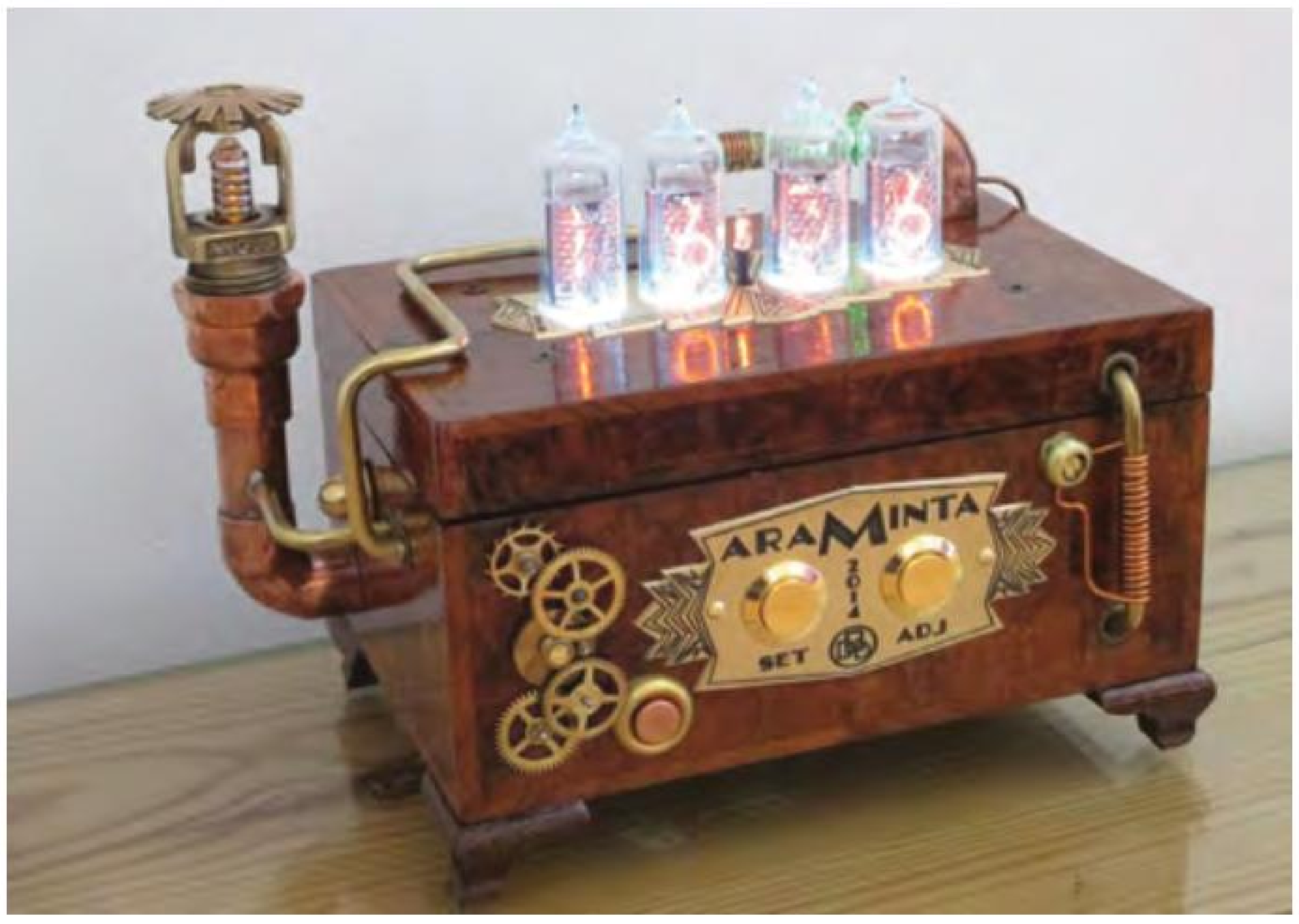

Fig.2. The Araminta Clock (Source: Bad Dog Designs)

Paul told me that the weird and wonderful umbrella-fan-thingy sticking up in the air is actually the sprinkler assembly from an antique fire extinguishing system. Who'd've thunk? Of course, I'm now looking around to see what bits and pieces I can find. The point is, I've decided I want to build my own *Steampunk Nixie Tube Chronograph*, but how would one set about doing this? Well, fortunately, Paul has proven to be a mine of useful information and contacts.

Bold as brass

I don't know about you, but I love the combination of old, dark, cherry wood and brass. To me it conveys a sense of Victorian something-or-other (I can't quite put my finger on it). The main thing is that it makes me feel good.

Now, when it comes to the case for my clock, I want – nay, I demand! – an antique look and feel. On the other hand, I hate the thought of taking something that's 100 years old and chopping it about. Fortunately, I have a friend called Bob here in town. Bob is a master carpenter. You wouldn't believe some of the things he's created. The long and short of it is that I'm going to ask Bob to create the most antique-looking cabinet for my clock.

When it comes to the brass panels, I started to think of my *Bodacious Acoustic Diagnostic Astoundingly Superior Spectromatic* (*BADASS*) display (**http://bit.ly/1I5ncTc**). The main front

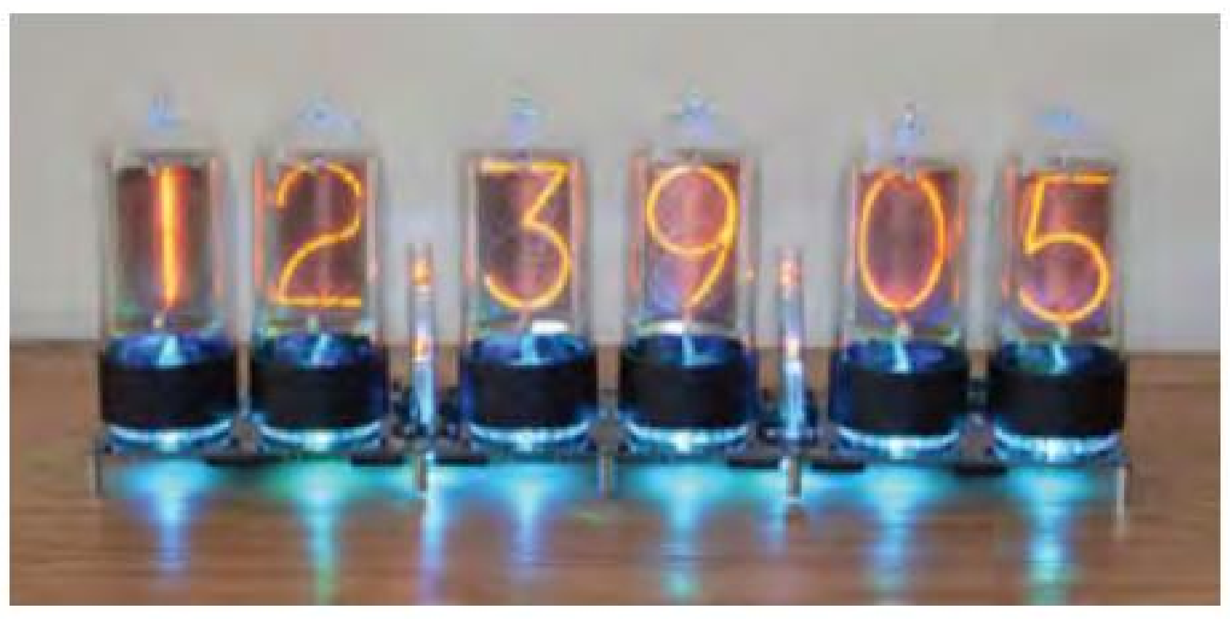

Fig.3. The Spectrum Kit for Z568M-type tubes (Source: PV Electronics)

panel of the display is formed from humble hardboard spray-painted to look like brass. It actually looks pretty good, but that's largely because the beast is so big that you tend to look at it from afar. In the case of my clock, people will be looking at it close up, so real brass is the only way to go.

I asked Paul how he sourced his brass panels, and he introduced me to the owners of Engraving Studios – Andy and Mandy Blackett (**http://bit.ly/1PXrtiF**). I understand that Mandy manages all of the machining while Andy is in charge of preparing the files and performing the final finishing and polishing. They've both been in the engraving business for more than 20 years, so they are getting pretty good at it by now. Anyway, Paul creates the vector drawings of what he wants, and then he hands the files over to Andy and Mandy for fabrication. I know where I'm going for the plates for my clock.

It's alive! It's alive!

When it comes to the electronics to drive the Nixie tubes, my first thought was to create them myself. After all, there's a wealth of information out there on the Internet – how hard could it be? Well, pretty hard, actually. I was chatting to my chum Ivan whose office is in the bay across from mine. Ivan used to repair Nixie tube-based equipment when he was in the American Air Force countless years ago.

Ivan amused himself by telling me horror stories of all the things that could go wrong and explaining how tricky it can be to get things right. Once again, Paul came to the rescue by introducing me to Pete Virica who is the owner of PV Electronics (**http://bit.ly/1GFVUk3**).

Arrgghh – yet more Nixie tube clocks to drool over. I ended up chatting with Pete on the phone. It turns out that he caught the Nixie tube bug ages ago. In fact, he loves working with these little rascals so much that about 10 years ago he decided to devote himself to taming their wily ways full time (this might explain why he was still at his desk when I called him at 10:00pm).

Actually, just a few minutes ago at the time of this writing, I placed an order on Pete's website for one of his latest and greatest Spectrum Kits (Fig.3) that's fine-tuned for working with Z568M-type tubes (**http://bit.ly/1X6HzGf**).

But why am I so set on basing my clock on Z568M-type tubes? Ah, well, therein lays a story...

Bigger is better

One of the problems with looking at photographs of things is that you sometimes fail to get a good impression of their true dimensions. In the case of the Turing and Araminta Clocks shown above, for example, my knee-jerk reaction was to assume that these were fairly hefty units. In reality, they are smaller than you might expect… because their Nixie tubes are smaller than you might think.

I'm not sure why, but when you look at a photo of a Nixie tube, you tend to unconsciously compare it to something like a light bulb, and then you mentally scale everything else from there. In reality, most Nixie tubes are only around 50mm tall and 25mm in diameter. However, it turns out that there's a tube called the Z568M that was made in East Germany in the 1960s. This is a giant amongst nixie tubes – it's 100mm high and boasts digits that are 50mm tall.

The problem is that no one is making these anymore, so those of us who want to use them in our clocks are forced to scrabble for them in a most unseemly way. Or so I thought. Yes, you guessed it, Paul has the answer. He introduced me to Dalibor Farny from the Czech Republic (**http://bit.ly/1PDJmRm**). All I can say is that I am in total awe of Dalibor because he creates his own Nixie tubes – from scratch (Fig.4).

And these aren't just any old Nixie tubes (as if there is such a thing); these gorgeous beasts are pin-compatible with the original Z568M tubes. Dalibor says that he thinks the Z568M is one of the most beautiful Nixie tubes ever made. He loves its vintage font, its inner structure, and what he describes as 'its eye-catching proportions.' All of these features combined to prompt Dalibor to create his R|Z568M tubes, where the 'R' stands for 'Resurrection.'

But wait, because... believe it or not... there's more. Dalibor's tubes typically have aluminium bases as shown in Fig.4. Furthermore, when it comes to the tube's internal structures, the anode at the back of the tube and the metal cage surrounding the digits are typically made out of steel.

Well, I discovered that Dalibor is creating a special set of tubes with bronze bases and copper anodes/cages for Paul. OMG! I cannot even imagine how amazing these are going to look. When I first heard this news, I almost embarrassed myself with an unfortunate accident. Of course, I didn't want to overstep my welcome, so I asked Paul if he would mind me commissioning a set of these tubes for myself, and he graciously acquiesced. I then talked to Dalibor who says that he's fully loaded at the moment, but that he will start work on my tubes in a couple of weeks, which will give me time to build my kit and start planning the cabinet.

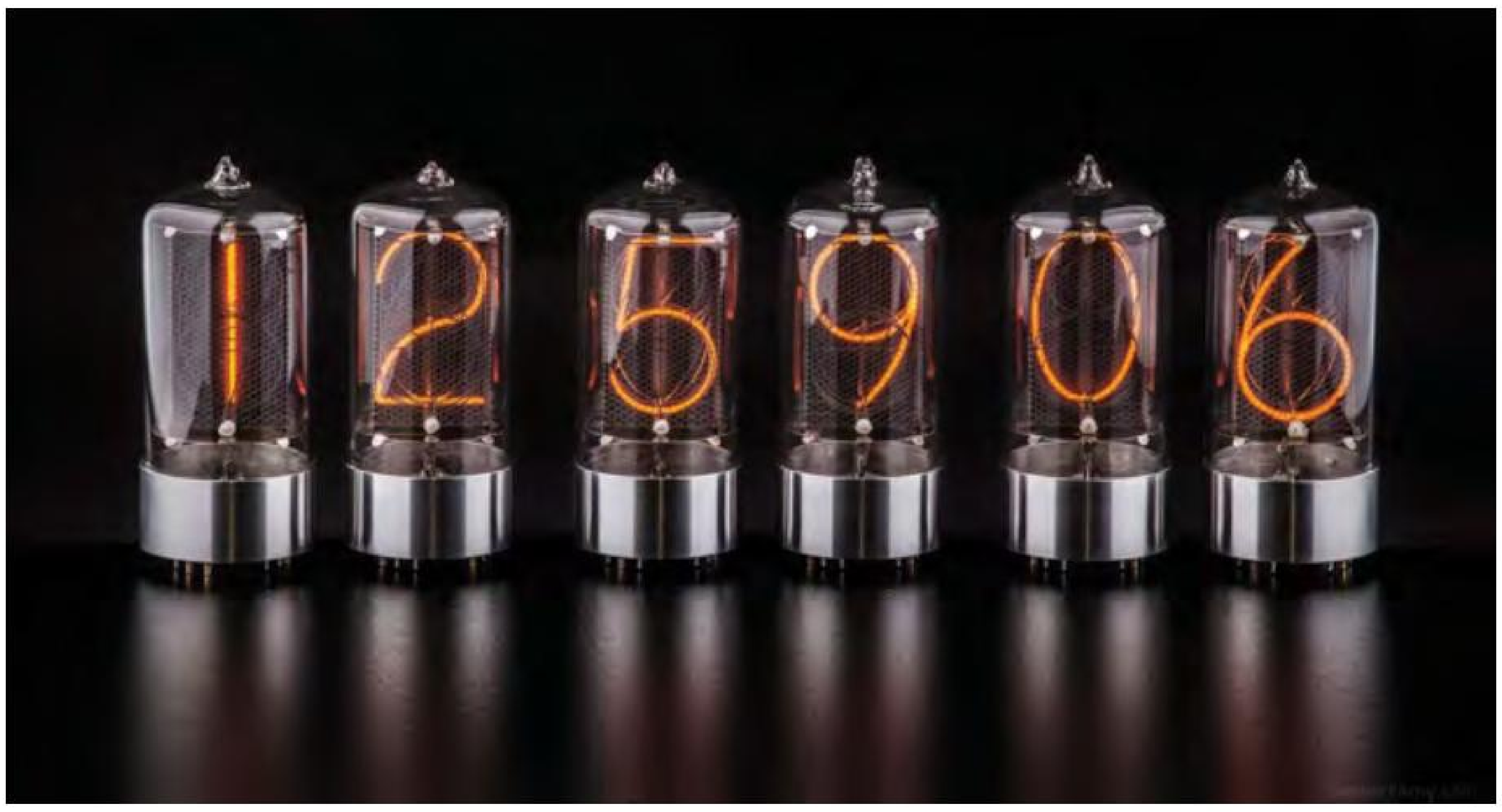

Fig 4. Hand-crafted Nixie tubes (Source: Dalibor Farny)

What can I say? I LOVE this stuff. I will, of course, keep you posted about my progress in a future column. Until then, have a good one!

Any comments or questions? – please feel free to send me an email at: **max@CliveMaxfield.com**

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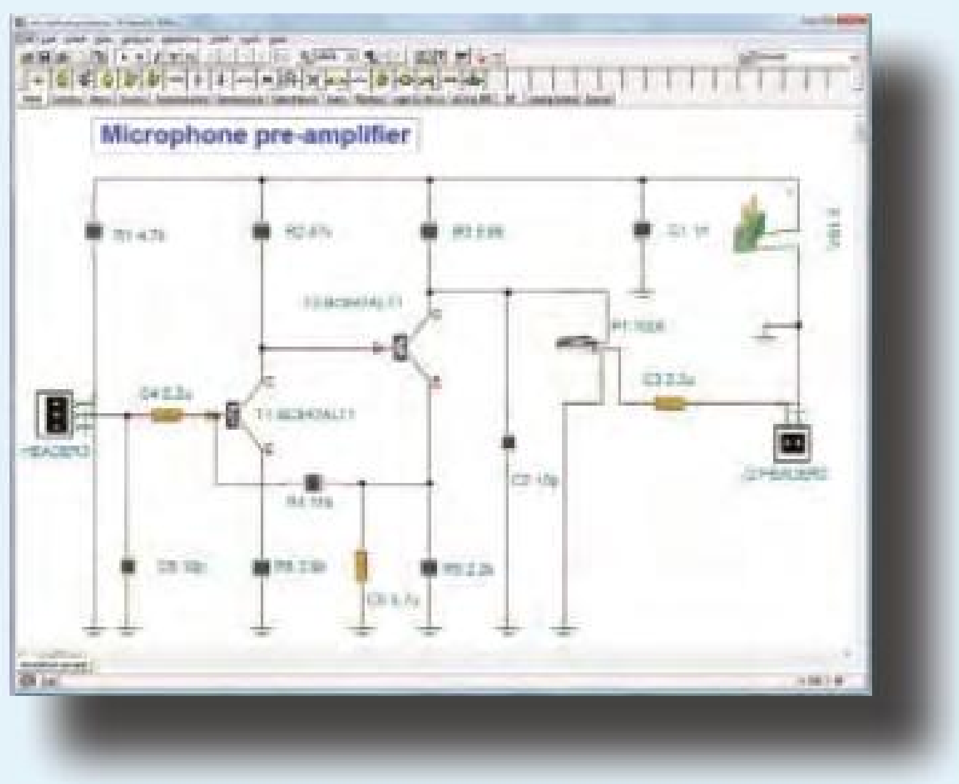

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Also included are 29 *PIC N' Mix* articles, also republished from *EPE*. These provide a host of practical programming and interfacing information, mainly for those that have already got to grips with using PIC microcontrollers. An extra four part beginners guide to using the C programing language for PIC microcontrollers is also included.

The CD-ROM also contains all of the software for the *Teach-In 2* series and *PIC N' Mix* articles, plus a range of items from Microchip – the manufacturers of the PIC microcontrollers. The material has been compiled by Wimborne Publishing Ltd. with the assistance of Microchip Technology Inc.

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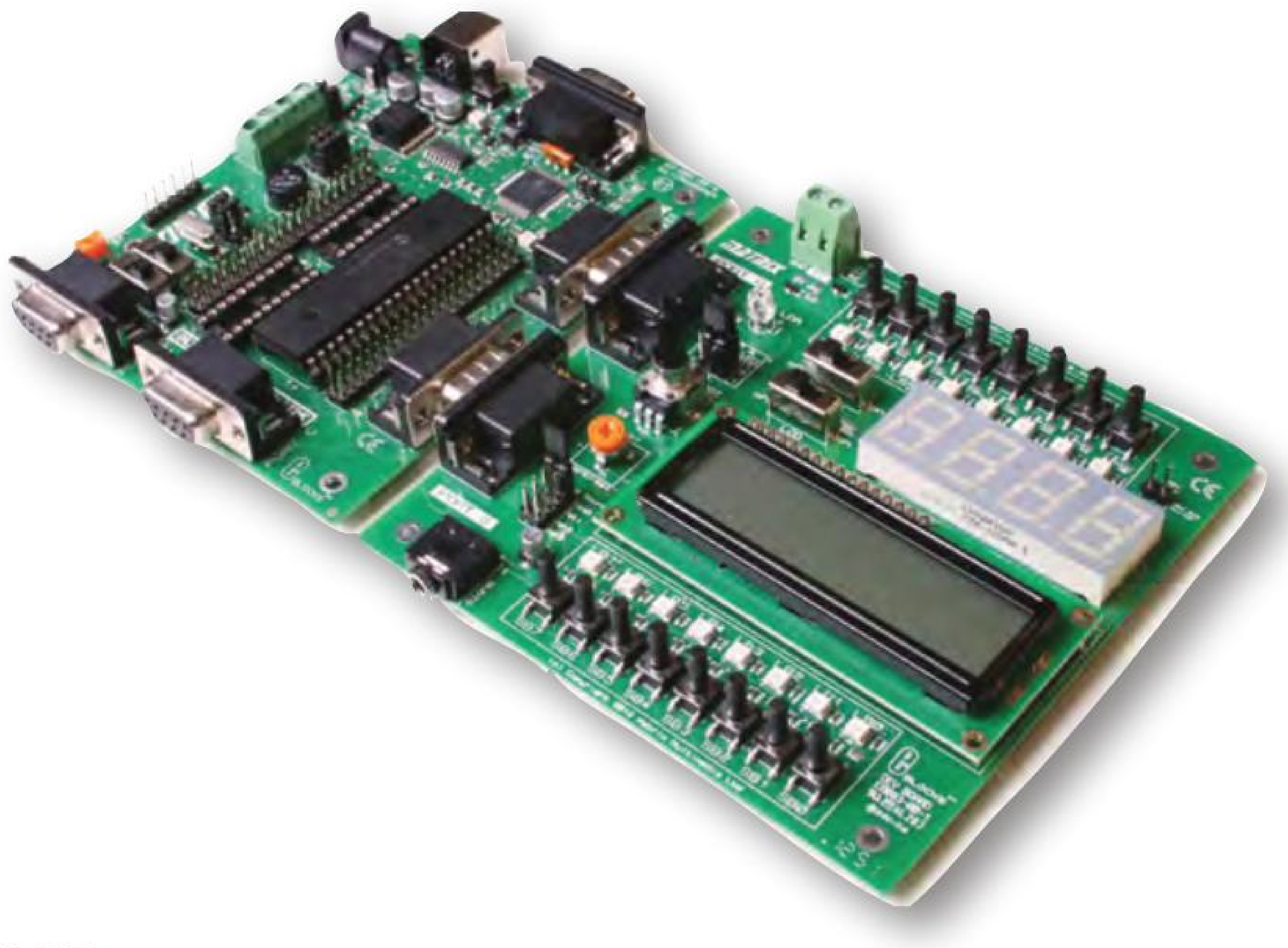

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SOFTWARE

ASSEMBLY FOR PICmicro V5

(Formerly PICtutor)

Assembly for PICmicro microcontrollers V3.0 (previously known as PICtutor) by John Becker contains a complete course in programming the PIC16F84 PICmicro microcontroller from Arizona Microchip. It starts with fundamental concepts and extends up to complex programs including watchdog timers, interrupts and sleep modes.

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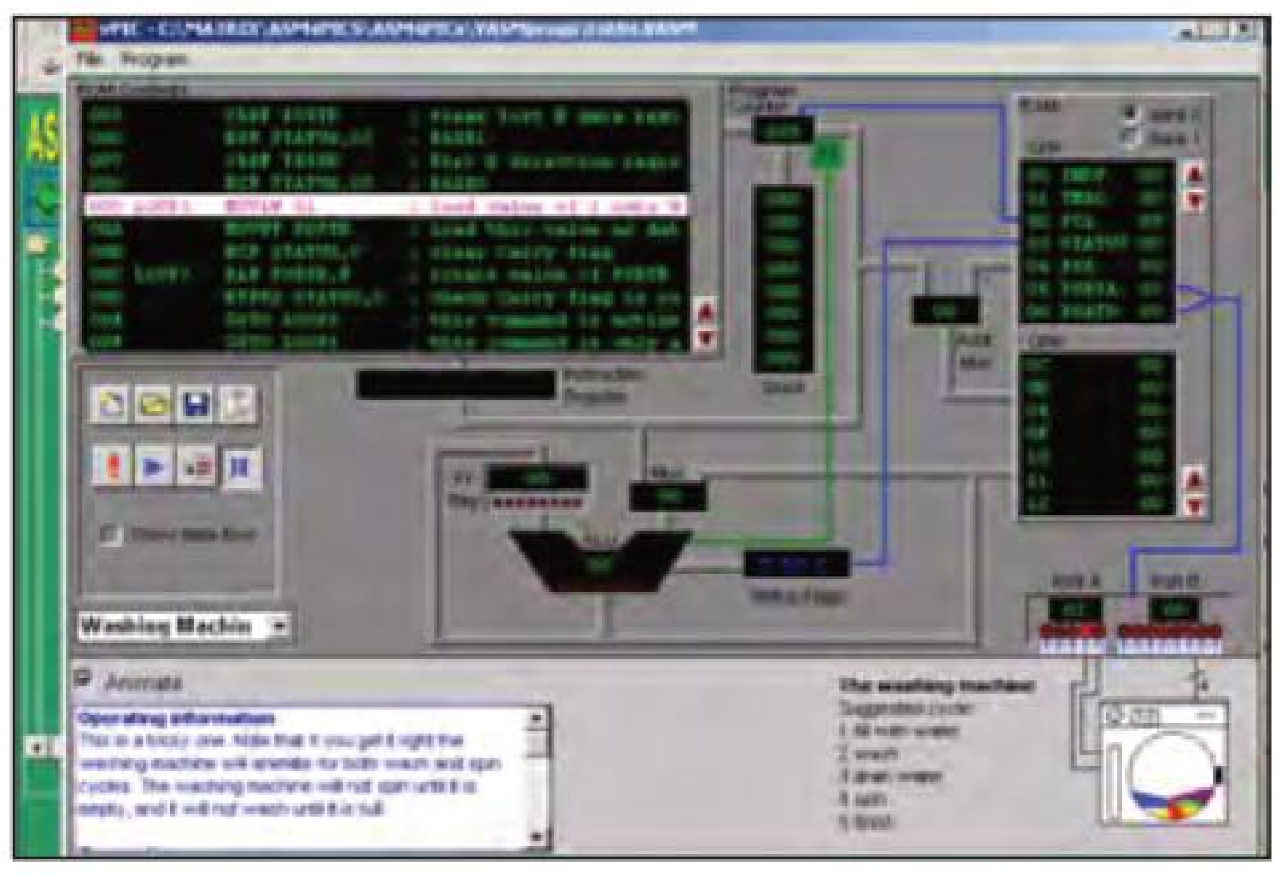

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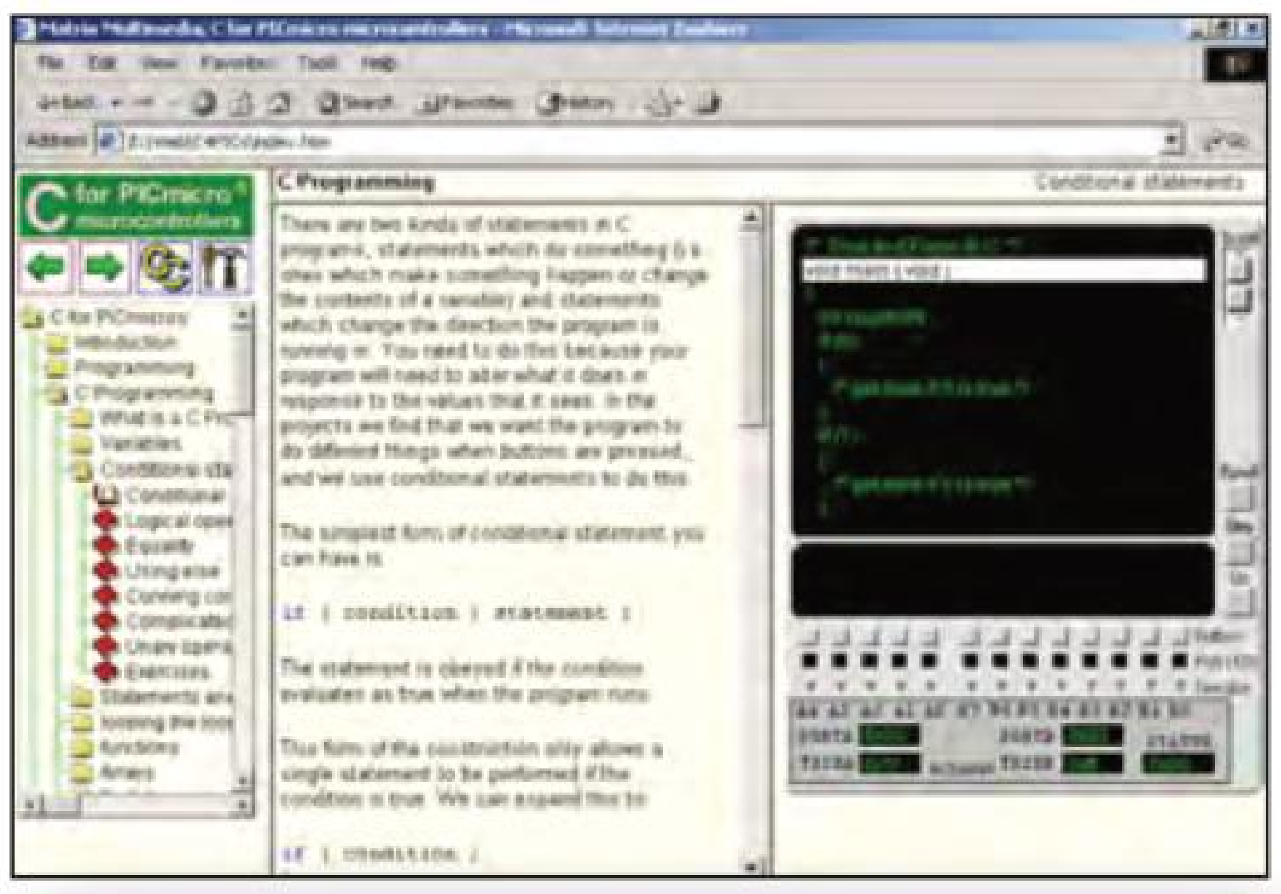

Minimum system requirements for these items: Pentium PC running, 2000, ME, XP; CD-ROM drive; 64MB RAM; 10MB hard disk space.
Flowcode will run on XP or later operating systems

FLOWCODE FOR PICmicro V6

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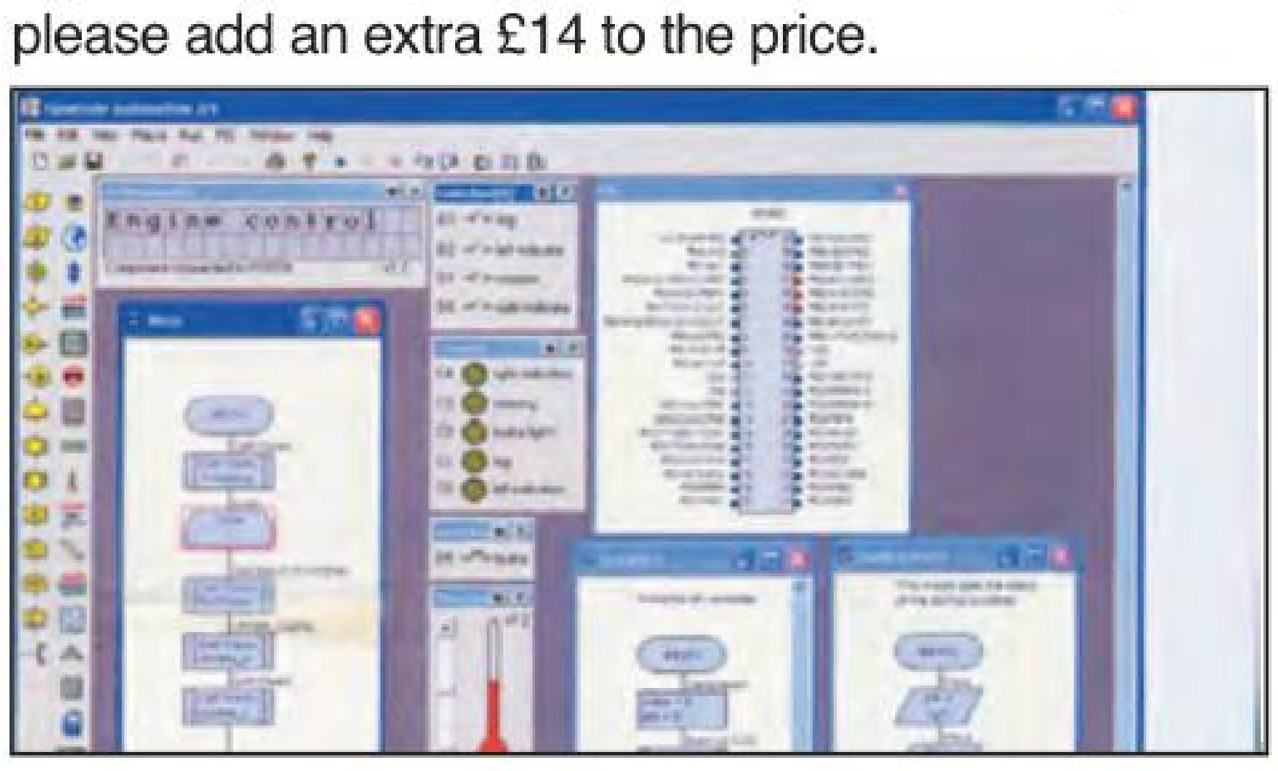
Please note: Due to popular demand, Flowcode PICmicro, AVR, DSPIC, PIC24 & ARM V6 are now available as a download. Please include your email address and a username (of your choice) on your order. A unique download code will then be emailed to you. If you require the CDROM as a back-up then please add an extra £14 to the price.



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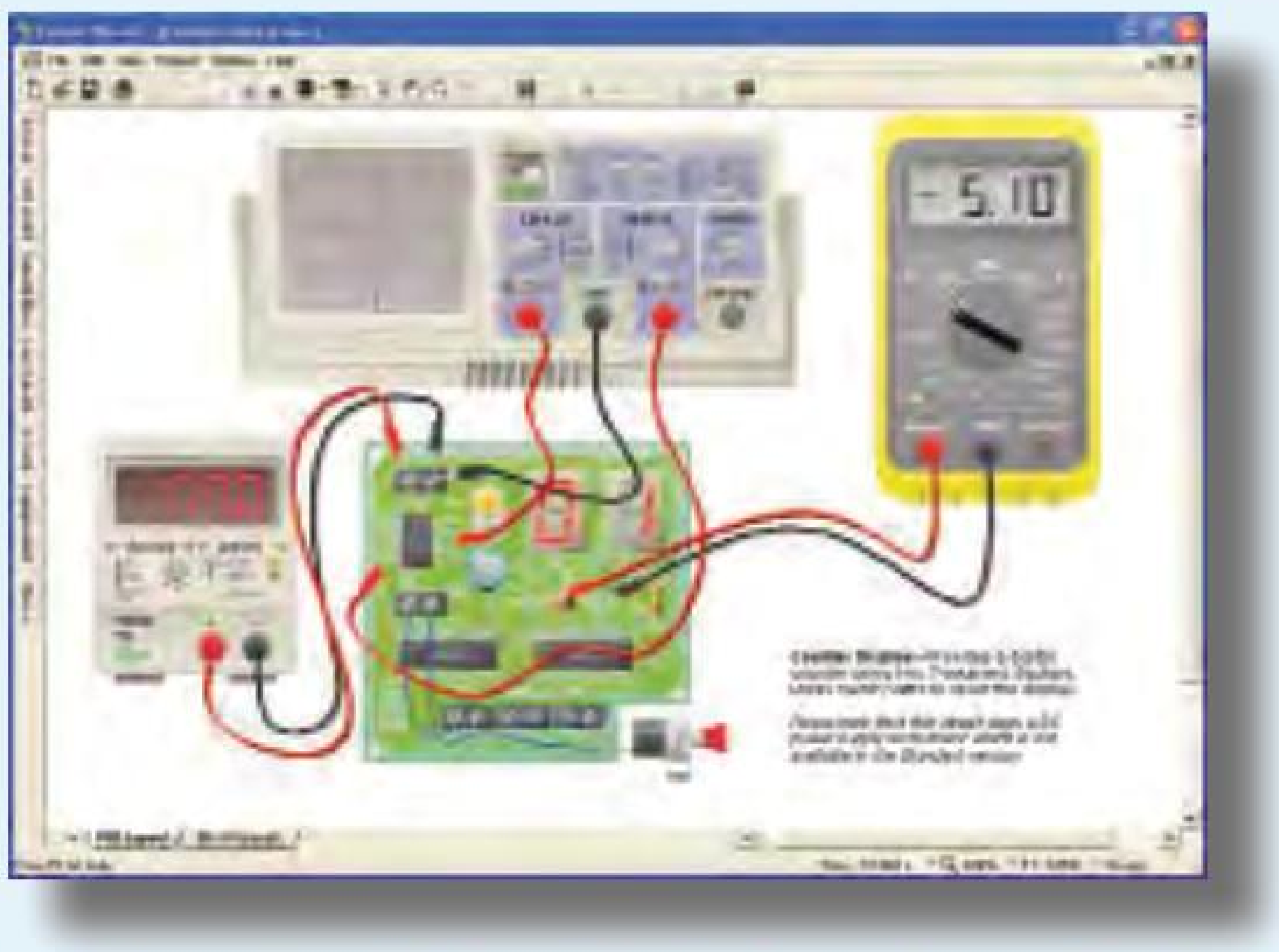

This software can be used with the *Jump Start* and *Teach-In 2011* series (and the *Teach-In 4* book).

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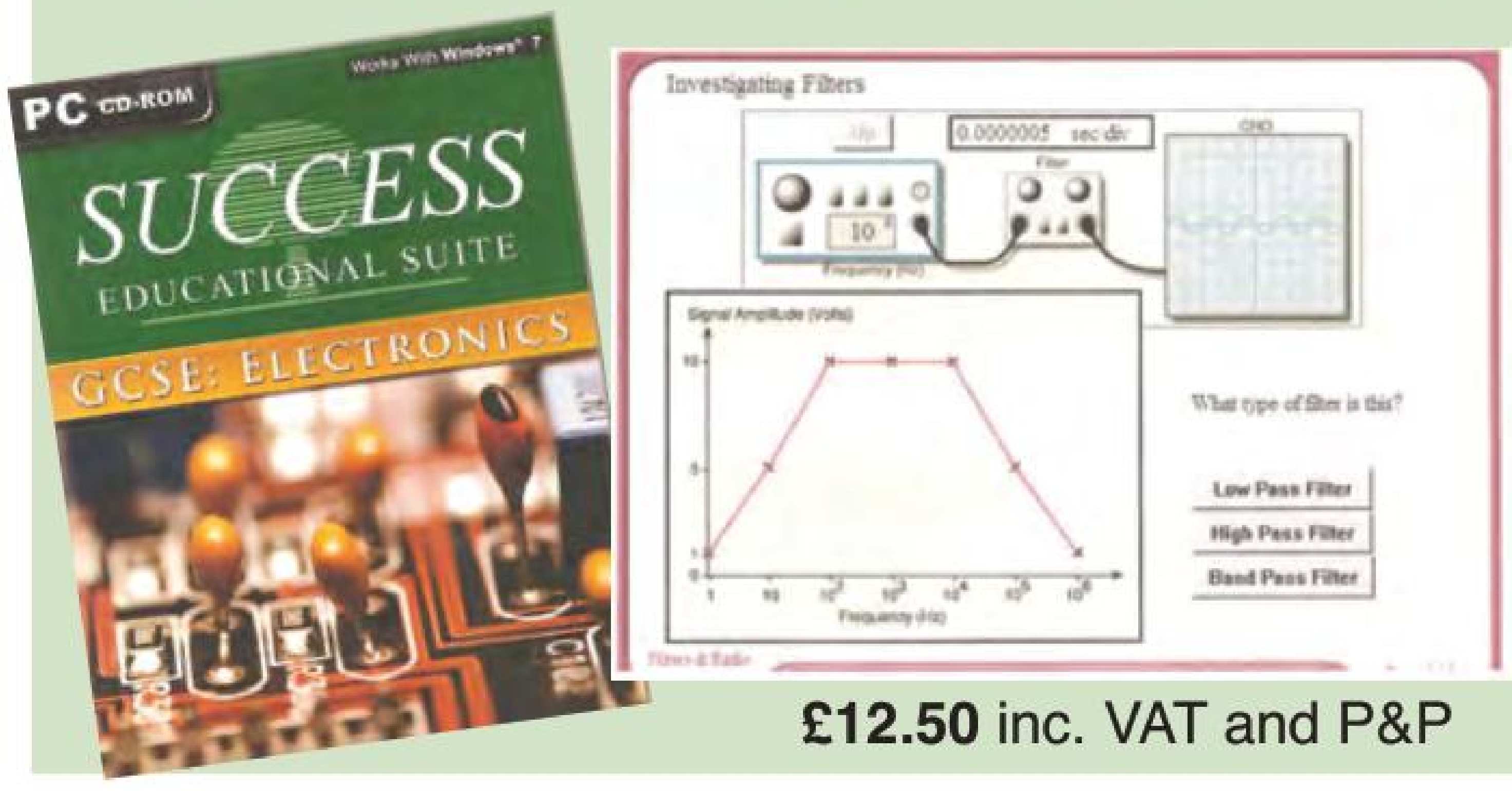

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READOUT

Matt Pulzer addresses some of the general points readers have raised. Have you anything interesting to say?

Drop us a line!

All letters quoted here have previously been replied to directly

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☆ LETTER OF THE MONTH ☆

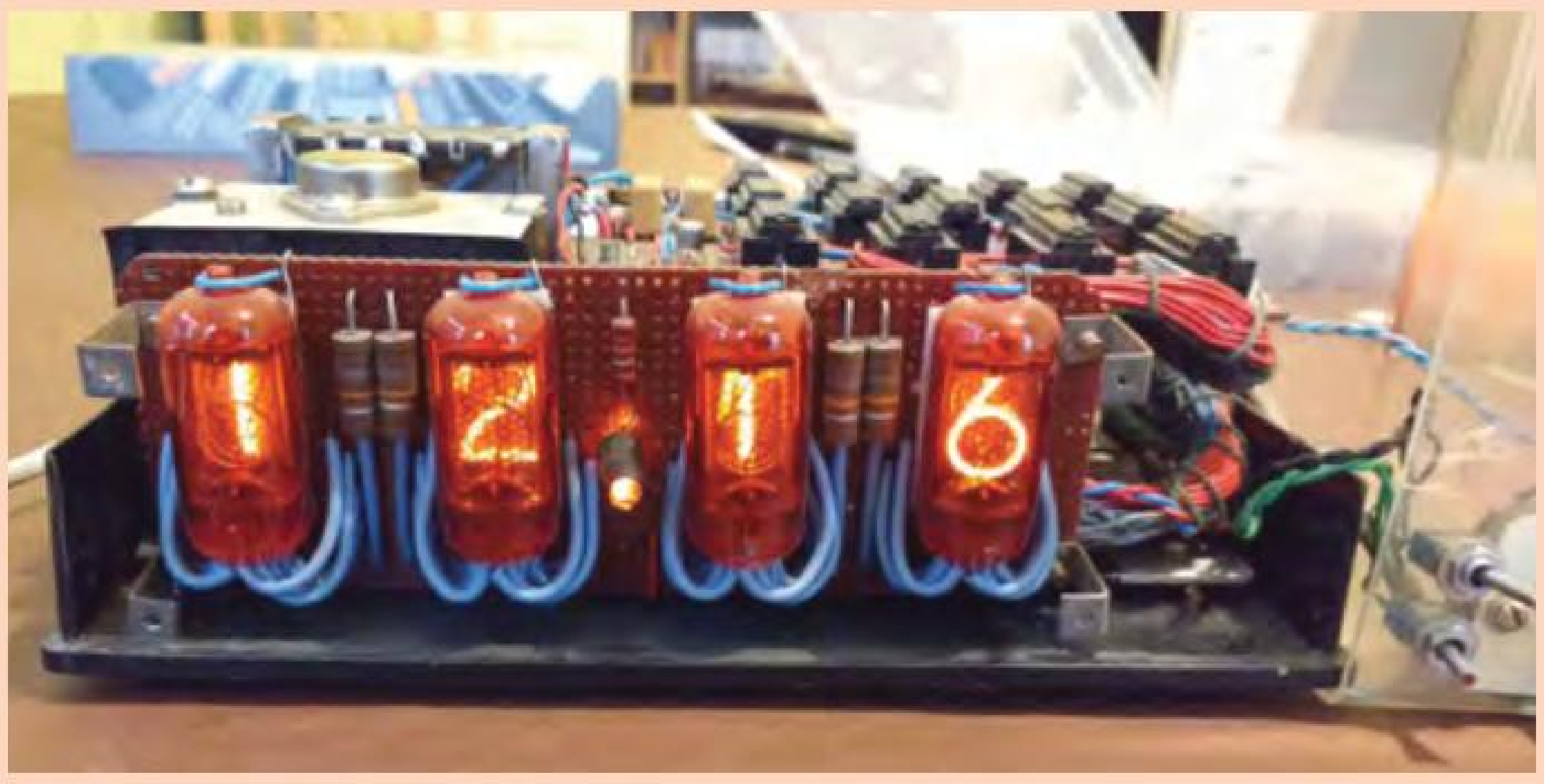
1970s Nixie clock

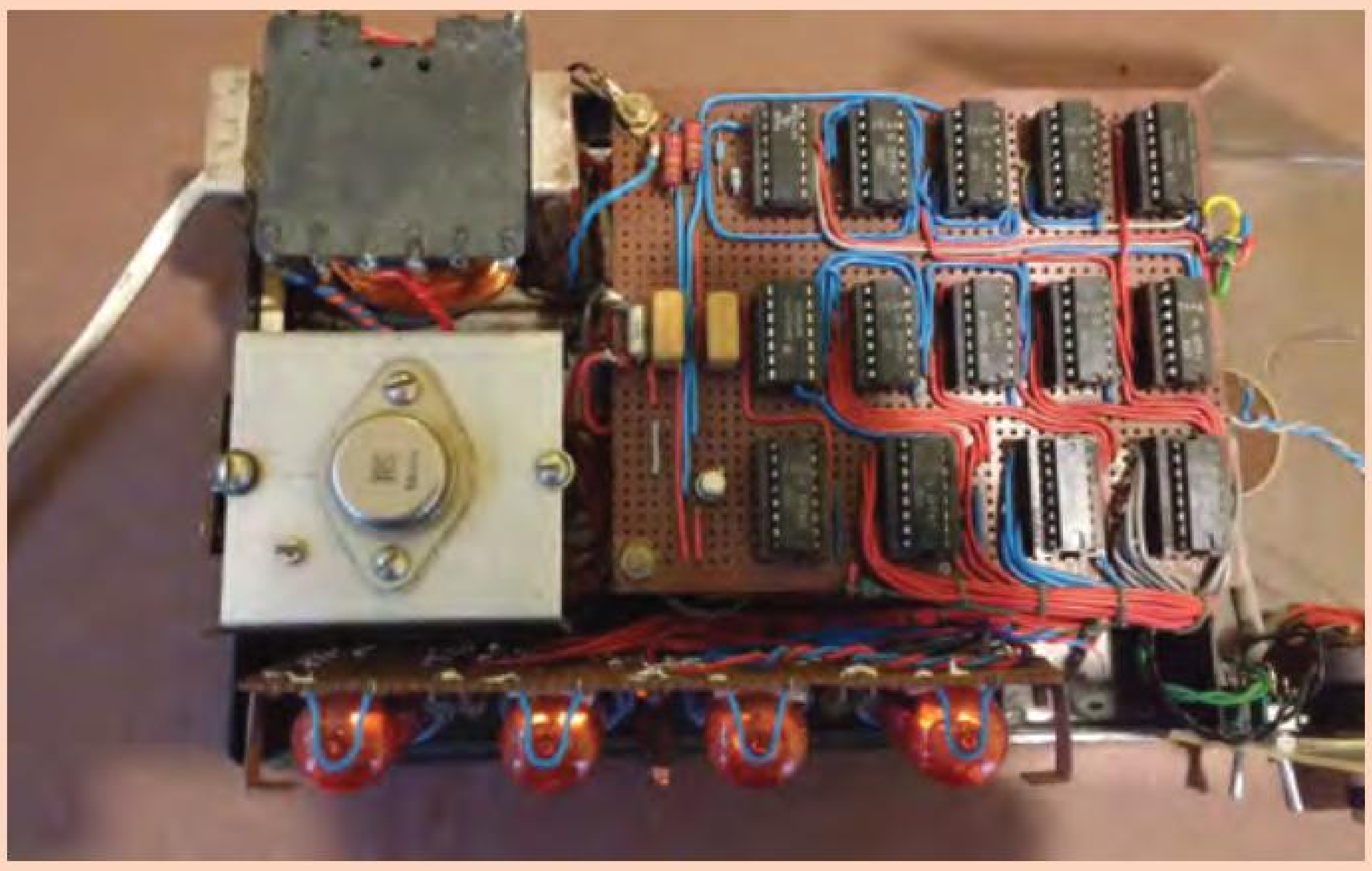
Dear editor

First, thank you for the superb *Everyday Practical Electronics* magazine, which has been a great way for me to keep up to date with electronics since my retirement a few years ago.

I thought I would drop you a line about the *6-Digit Retro Nixie Clock* in your February 2016 issue. It brought to mind a 4-Nixie Clock that I built way back – if memory serves, 1974-ish – from a circuit that I believe was in *Practical Electronics* magazine at around that date.

I had a root around in the loft and I found the clock. Now, bearing in mind that it had not been used and had been hidden away up in the loft for more than 40 years you wouldn't expect much from it would you? But amazingly, apart from a wire that had come adrift from a 5V rail indicator LED and a slightly dodgy SN7400 chip, which I replaced, it all worked absolutely fine – not bad for an old timer!





In the photographs I have removed the top part of the clear plastic case (an old recycled Kodak camera presentation box) to give you a better view of the vintage workings.

Last, but not least, thanks to *PE* and *EPE* magazines for bringing back some memories.

Brian Gumbleton, by email

Matt Pulzer replies:
Nice work Brian, and it just goes to show that a good design, well made can last a very long time. Thank you for sharing your electronics memories with us.

Newcomer to electronics

Dear editor

I am a relative newcomer to electronics. I know something about the function of various components such as resistors transistors capacitors and diodes, but I have never built a circuit. Is this magazine suitable for a novice such as myself?

Roger Williamson, via email

Matt Pulzer replies:
Thank you for your enquiry. We like to think that EPE *is both an excellent introduction for 'novices', as well as a satisfying magazine for 'old hands'. Inevitably, the more advanced articles and projects are a challenge for the less experienced, but one of the great pleasures of electronics is that there is always something new and interesting to discover.*

We regularly run series called Teach-In *that are suitable for beginners –* Teach-In 4 *and* Teach-In 5 *are particularly appropriate for those who are new to the subject. These are available from our shop:* **www.epemag.wimborne.co.uk/acatalog/Electronics_Teach_In_Books.html**

If you are interested in the popular Raspberry Pi then Teach-In 6 *is a thorough introduction, but requires a little more experience in electronics than* Teach-In 4 *and* Teach-In 5.

Last year, our Teach-In *series described how to build an impressive Hi-Fi amplifier from just discrete components (ie, no integrated circuits) and we are now looking at the popular Arduino microcontroller.*

IF YOU HAVE A SUBJECT YOU WISH TO DISCUSS IN READOUT PLEASE EMAIL US AT:

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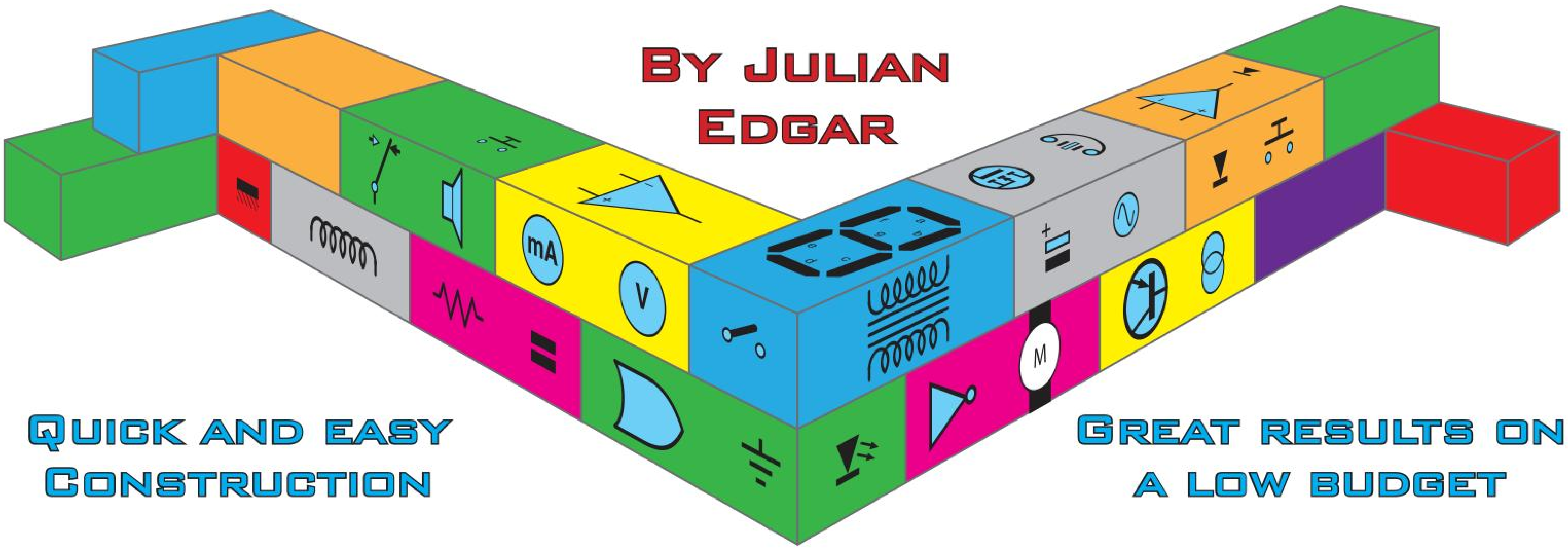
Electronic Building Blocks



By Julian Edgar

Quick and easy construction

Great results on a low budget

PIR Sensor Module

Large complex projects are fun, but they take time and can be expensive. Sometimes you just want a quick result at low cost. That's where this series of *Electronic Building Blocks* fits in. We use 'cheap as chips' components bought online to get you where you want to be... FAST! These projects range from around £15 to under a fiver... bargains!

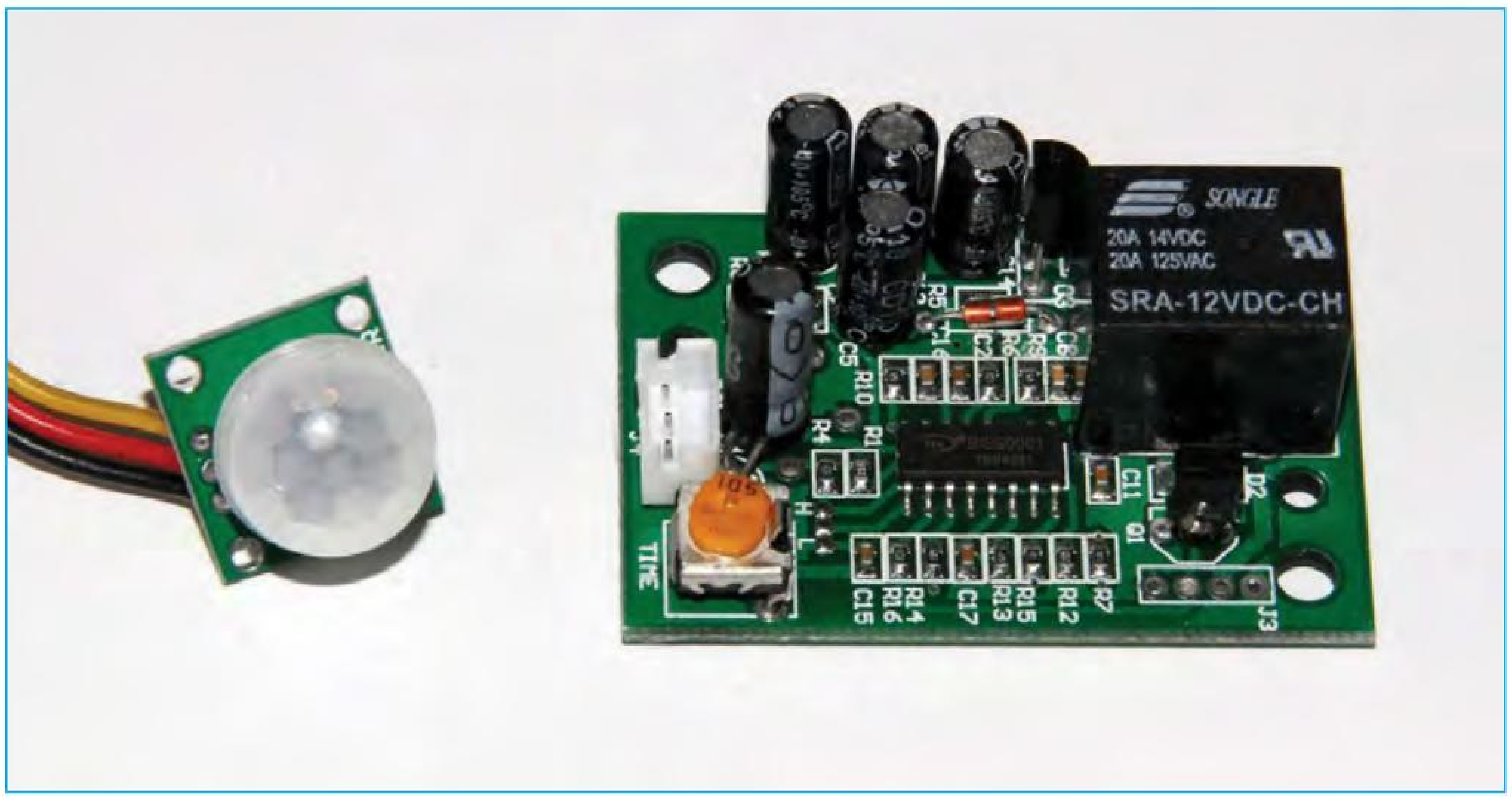


Fig.1. The PIR sensor module comprises a small PCB, 45 × 30mm. It connects to a supplied sensor via a 150mm-long cable. A relay output is provided, so it is easy to use the module to trigger lights or buzzers.

PIR Sensor Module

Here's a great off-the-shelf module that can be used in 'serious' applications, such as security or automatic light operation – or for fun applications, like catching your son or daughter sneaking into your lolly or biscuit cupboard!

Two PCBs

The module comprises a small board, just 45 × 30mm in size. The sensor, mounted on its own 15mm square board, comes supplied with about 150mm of cable and is fitted with a plug. A matching socket is provided on the main board, so connecting the two requires simply plugging the sensor into the socket. (Note that this socket is the one nearest to the adjustment pot.)

Connections

Another socket, located near to the relay, is provided on the board and this comes with a three-wire, flying lead cable. The wires are colour-coded:

Red	DC +12V input
Black	negative
Yellow	DC +12V output

The output is provided by an on-board relay that's nominally rated at 20A. However, the board tracks would not cope at all well with this much current, so perhaps don't load it with more than an amp or so.

Output relay on time

Also provided is an on-board pot. This does not, as you might first expect, adjust the sensor sensitivity, but instead alters the time the output stays energised after the sensor has last detected movement. This output is variable in the range 15 seconds to 30 minutes. Note that clockwise = shorter duration.

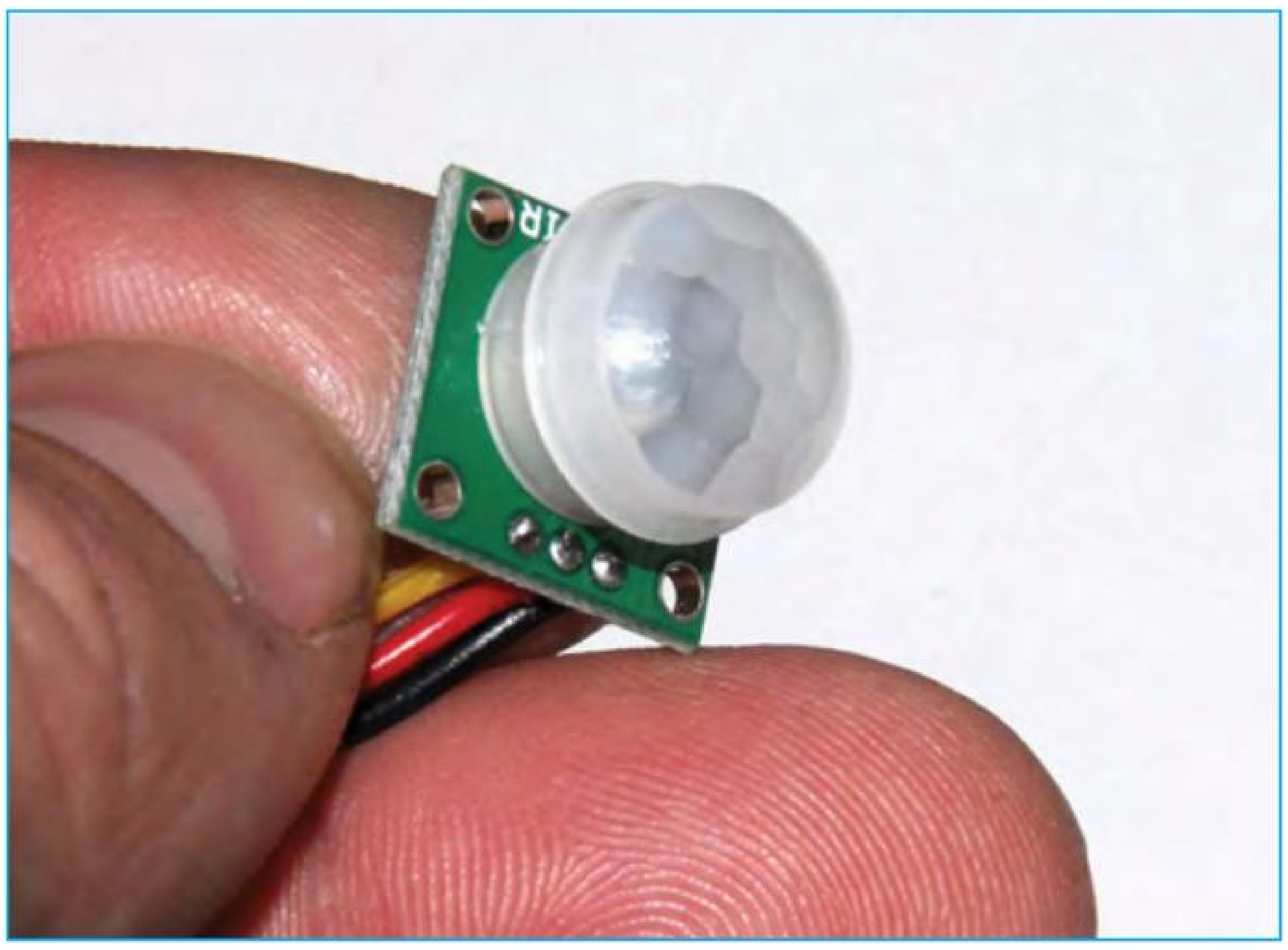


Fig.2. The sensor is mounted on its own 15mm square board. It's very sensitive and has a wide-angle sensing field.

Battery operation

The standby current is claimed to be less than 50µA – and we measured 42µA when the module was powered from a 9V battery. That means the battery life when the device is in an un-triggered state should be excellent.

Operation

The sensor is sensitive and, if located in an upper corner, will detect movement anywhere in a large room.

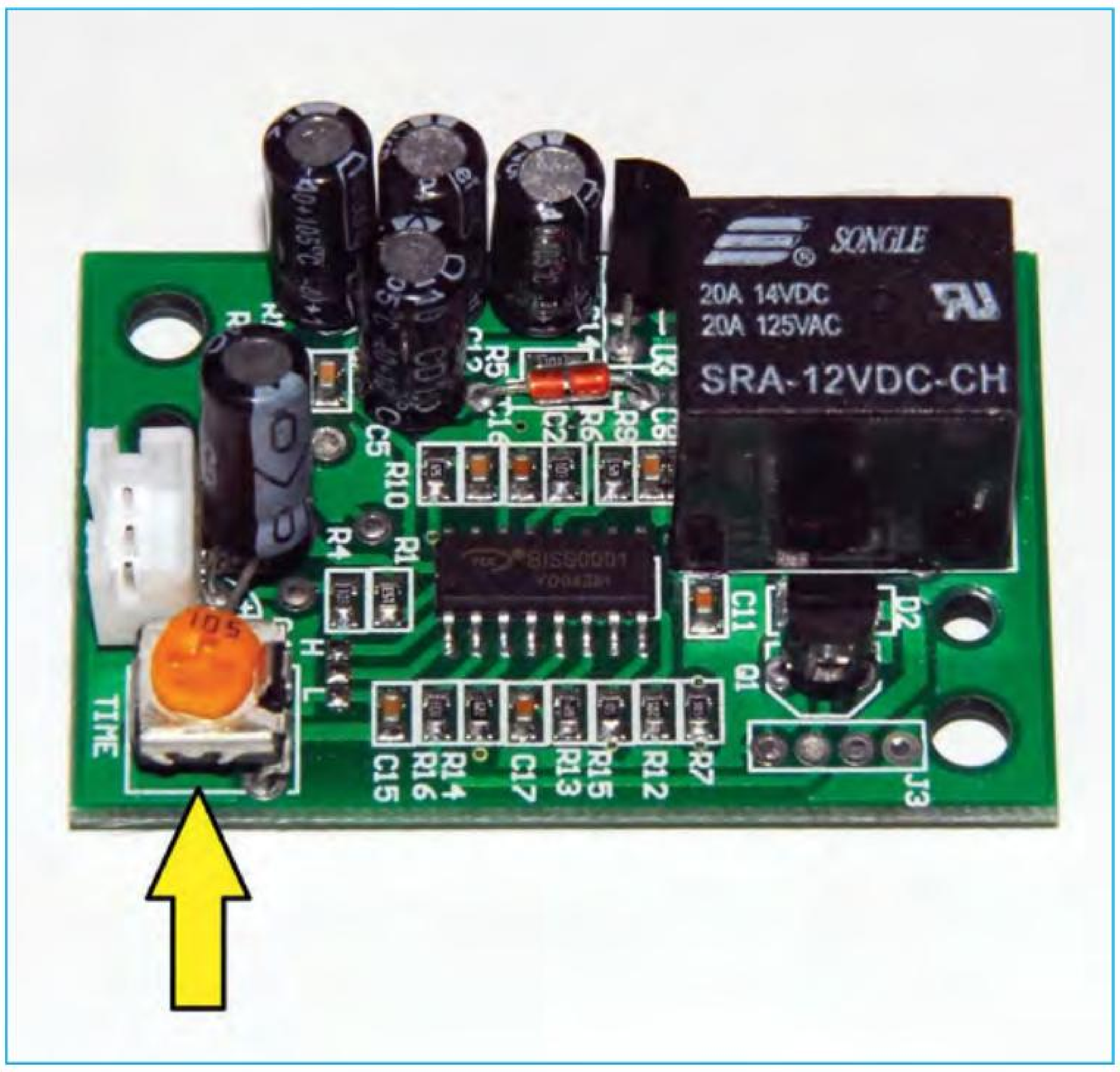


Fig.3. This on-board pot allows the output time of the relay to be set. Minimum actuation time is 15 seconds and maximum is 30 minutes.

We chose to power the module from a 9V battery and trigger a high intensity LED. That very simple set-up illuminates cupboards when they are opened. Replace the LED with a buzzer and the device can be used to detect people raiding lolly jars and the like!

Conclusion

A great module with plenty of real-world uses that will help to keep you safe, or at least entertained!

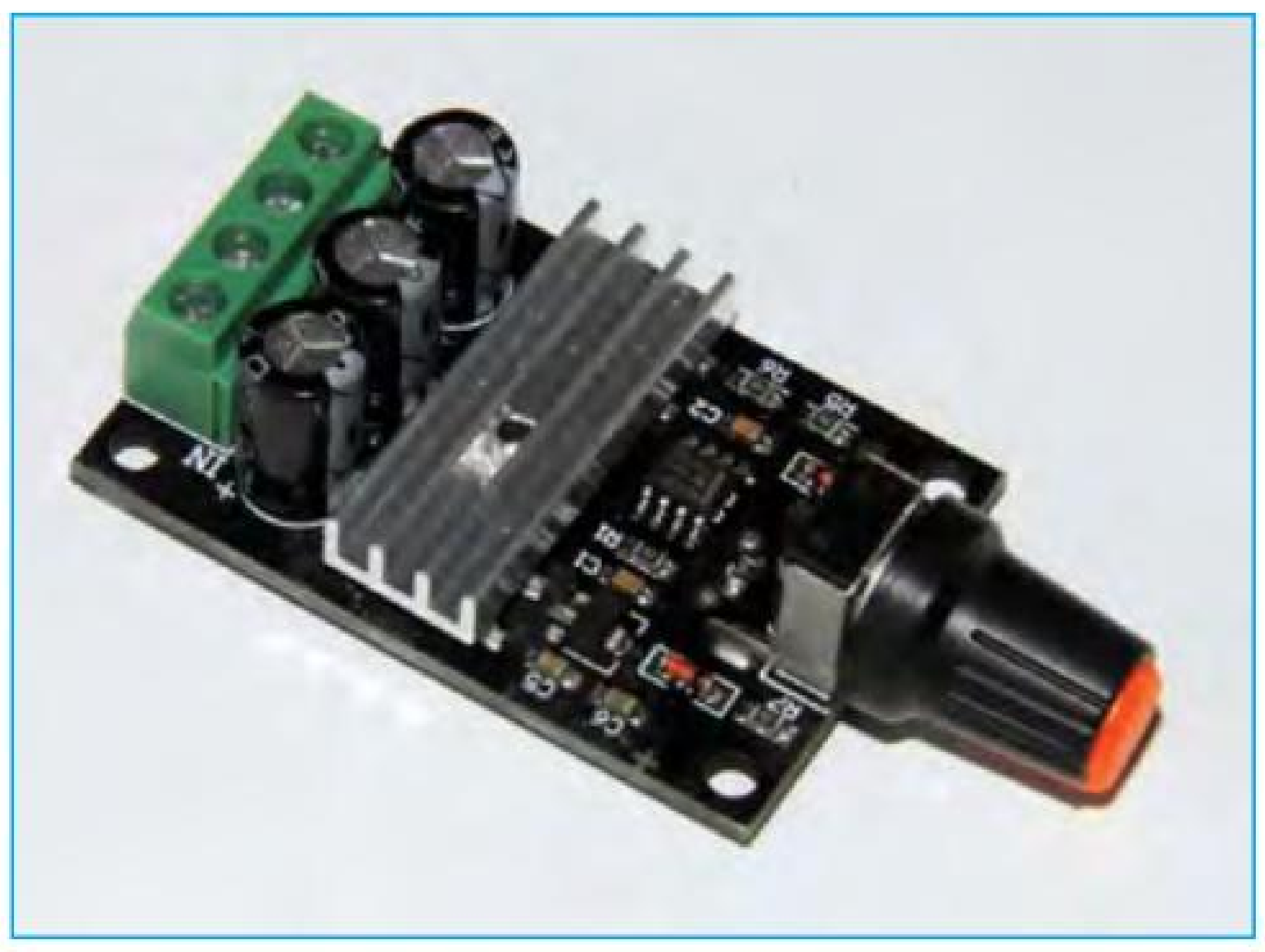
Sourcing

This module will cost less than £4, delivered to your letterbox. At the time of writing, it could be found at: **www.ebay.co.uk**, item 321490686185.

You can also find it on eBay by searching under 'DC 12V PIR sensor High sensitivity PIR Module with Relay control'.

Next month

Here is an absolute beauty – a tiny, efficient and cheap *Variable PWM Power Module*. Hook it up to a DC fan, and you can control the fan speed via the supplied knob. Use it with filament light bulbs and you can control their brightness, steplessly and without flicker. All this is in our next super *Electronic Building Block* article.



Next month – use this superb PWM module

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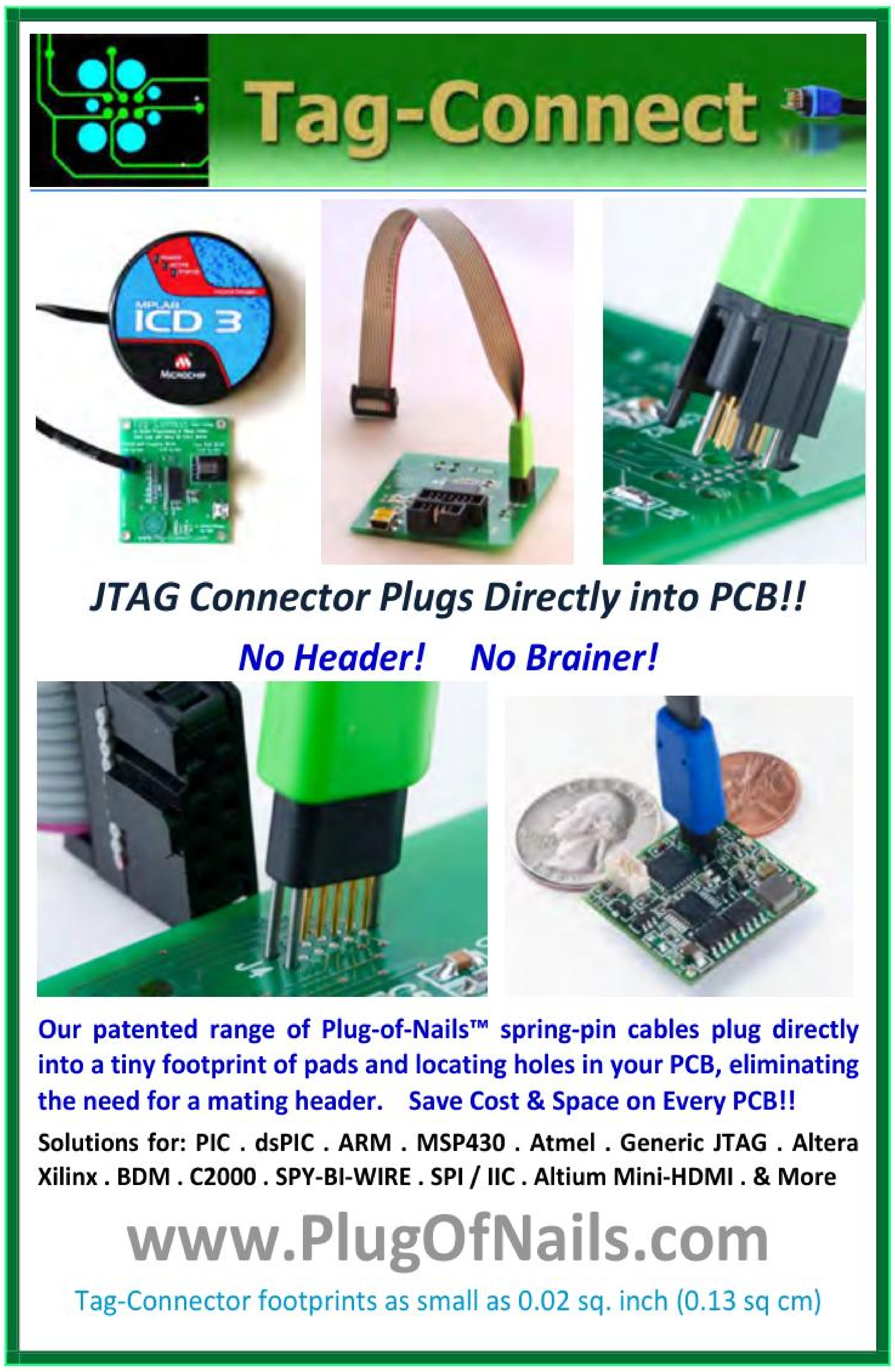

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Basic printed circuit boards for most recent *EPE* constructional projects are available from the *PCB Service*, see list. These are fabricated in glass fibre, and are drilled and roller tinned, but all holes are a standard size. They are not silk-screened, nor do they have solder resist. Double-sided boards are **NOT plated through hole** and will require 'vias' and some components soldering to both sides. **NOTE: PCBs from the July 2013 issue with eight digit codes** have silk screen overlays and, where applicable, are double-sided, plated through-hole, with solder masks, they are similar to the photos in the relevent project articles.

All prices include VAT and postage and packing. Add £2 per board for airmail outside of Europe. Remittances should be sent to **The PCB Service, Everyday Practical Electronics, Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset BH21 1UU. Tel: 01202 880299; Fax 01202 843233; Email: orders@epemag.wimborne.co.uk. On-line Shop: www.epemag.com**. Cheques should be crossed and made payable to *Everyday Practical Electronics* **(Payment in £ sterling only)**.

NOTE: While 95% of our boards are held in stock and are dispatched within seven days of receipt of order, please allow a maximum of 28 days for delivery – overseas readers allow extra if ordered by surface mail.

Back numbers or photocopies of articles are available if required – see the Back Issues page for details. WE DO NOT SUPPLY KITS OR COMPONENTS FOR OUR PROJECTS.

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*** See NOTE left regarding PCBs with eight digit codes ***

Please check price and availability in the latest issue.
A large number of older boards are listed on, and can be ordered from, our website.

Boards can only be supplied on a payment with order basis.

EPE SOFTWARE

Where available, software programs for *EPE* Projects can be downloaded free from the Library on our website, accessible via our home page at:
www.epemag.com

PCB MASTERS

PCB masters for boards published from the March '06 issue onwards are available in PDF format free to subscribers – email **fay.kearn@wimborne.co.uk** stating which masters you would like.

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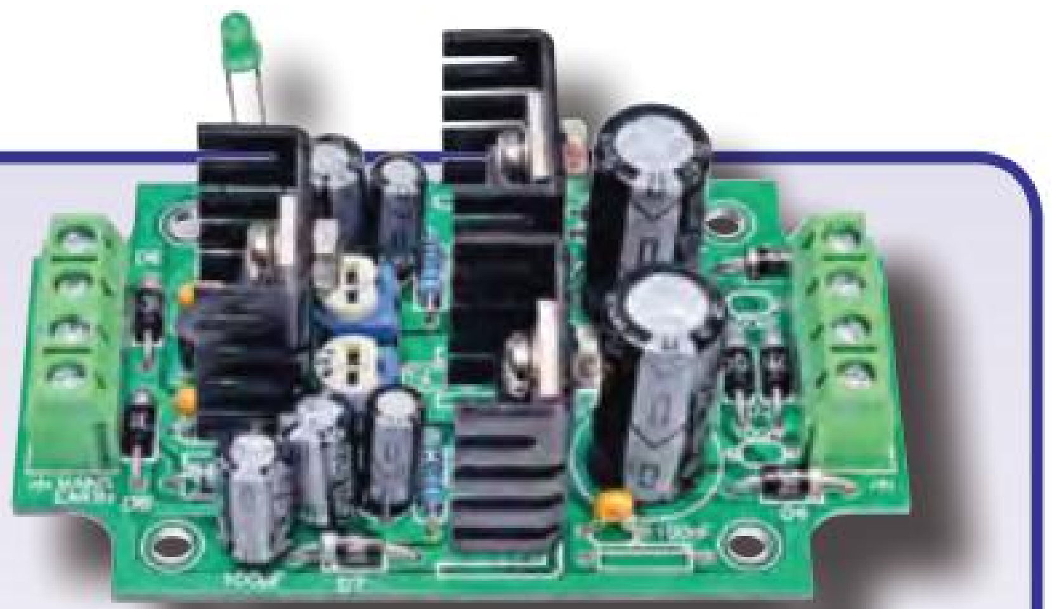
Next Month

Content may be subject to change



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Appliance Earth Leakage Tester

Used in conjunction with a digital multimeter, this *Appliance Earth Leakage Tester* checks the safety of earthed and double-insulated equipment. Most importantly, it tests equipment when it is powered from the 230VAC mains supply and operating normally.

2-Channel Balanced Input Attenuator for Audio Analysers and Digital Scopes

This project is designed to extend the measurement capabilities of low-cost USB test instruments like the QA400 Stereo Audio Analyser. It provides balanced/differential inputs for each channel in addition to unbalanced inputs, combined with three attenuation/measurement ranges: 1:1, 10:1 and 100:1.

Teach-In 2016 – Part 4

In April's *Teach-In 2016* we will look at ways in which the Arduino can sense and react to the real world. *Arduino Workshop* will examine the Arduino's analogue ports, while *Arduino World* introduces low-cost temperature sensors. Our programming feature, *Coding Quickstart*, explains the functions that will let you use serial communication via the Arduino's USB port. Finally, *Get Real* will show you how you can build a simple thermostatic controller.

PLUS!

All your favourite regular columns from *Audio Out* and *Circuit Surgery* to *Electronic Building Blocks*, *PIC n' Mix* and *Net Work*.

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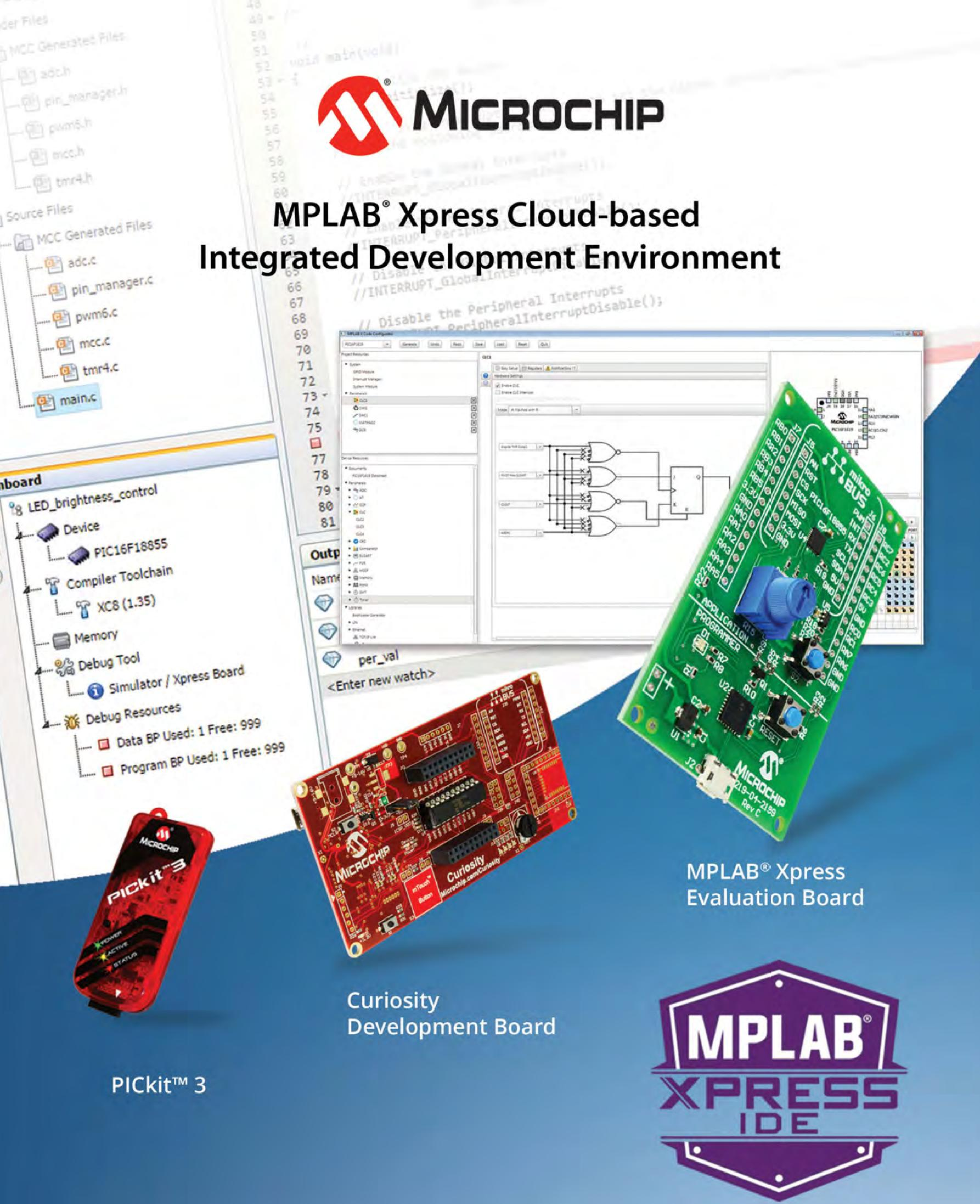

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